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ELECTRICITY
FOR
LOCOMOTIVE ENGINEERS

Being a Thorough Treatise on the Elementary Principles of Electricity and its Application to Railway Transportation

VOL. IX
ILLUSTRATED

BY
CALVIN F. SWINGLE, M. E.
AND A CORPS OF PRACTICAL MECHANICAL EXPERTS

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PREFACE.

This book is written principally for railroad men who are or may some day be in contact with the electrical machinery and apparatus, which is today installed on all steam roads, and with the machinery and apparatus which is being or will be installed by many roads with the intention of using electricity as a motive power on branches or even sections of their main line.

Nearly all roads use both telegraph and telephone in controlling train movement; all use telegraph and electric bells. Many roads are using electrically controlled block signals, and the use of automatic electric signals is rapidly increasing.

It will not be long before electricity will become the motive power in use by the roads entering the large cities on all their urban and suburban lines. The electric locomotive and motor car will supersede the steam locomotive.

No railroad man, engineer, conductor, fireman, baggageman, switchman, brakeman, towerman or any other, can afford to be ignorant of the subject of electricity. The men who know most about it will stand the best chance.

The men who study will possess knowledge of electricity that can not fail to be of immense advantage to them in the next few years.

It will make them more valuable to the companies, and keep them abreast of their rapidly developing profession.

It would be impossible to exaggerate the importance of such preparation being made by the men who wish to succeed. To be content to be ignorant of electricity and its application to motive power, is to be doomed, or to doom yourself to failure.

There are, however, many other men who are interested in electricity as applied to railroads and for such the book is also written.

Considering the recent date of the adaptation of electrical power to steam roads, all descriptions of old-fashioned machinery and apparatus which we would find in many electric light or street railway plants are omitted and the descriptions of apparatus to be found in large traction plants, whether inter-urban, branch or main line stations, will be described in full, and in such a way that it is hoped that any still newer types of machinery and apparatus, will be understood because of the fundamental knowledge gained by study of this book.

METHOD OF THE BOOK.

The author has endeavored to be honest as to what we know about electricity and what we think we know; also to tell the things a railroad man should know plainly.

The book consists of a series of lessons, each one of which should be learned before studying the next.

Each lesson is short enough to be studied at one time. When a reference is given to a lesson ahead it is to be simply read, not studied. In fact, the student need not look up the reference if he is in a hurry to finish the lesson.

These references will, however, be an extra help in making the lessons easily understood. Whenever a word or term is used for the first time it will be explained at once, in the text or by foot note, or else a reference ahead will be given. After a word has been used and explained no reference will be given.

The style is a series of questions and answers.

The questions are those which would be asked by a person seeking information about electricity and electric railroads, and the answers are those which would be given by one teaching electricity to the questioner.

Thus by learning the answers a person gains a knowledge of electricity and also the art of explaining things to other people. This is of inestimable value to any man, because when we are compelled to tell a friend "I know it but I can't explain it," we are apt to fall in that person's estimation. He either thinks that we do not know or will not tell.

Many of the questions in these lessons are ones which have actually been asked the author by acquaintances and students. He feels greatly indebted to the railroad men of one of the large terminals who, while receiving instructions from him in Electricity as Applied to Railroad Transportation, helped him wonderfully by their readiness to ask questions until they understood what was told them.

The book is not offered with a faint hope that it may succeed, but knowing that what it contains has helped a group of railroad men, it is hoped that, put in a book, it will reach more men and be of use to them.

The introductions to the lessons are those parts which prepare the student's mind for the lesson, and they contain information which can be told better in that way than by questions and answers.

Descriptions of apparatus and machinery are often given between lessons. These not only make the student familiar with the things described, but serve to fix the knowledge already attained. The study of these descriptions also reviews the knowledge previously acquired.

LESSON 1.

INTRODUCTION.

Exactly what electricity is we do not know, and indeed a practical man always dealing with the useful effects of electricity, applying these to the necessities and for the comfort of mankind, finds little time to wonder what electricity is.

We will omit the almost unanswerable question:—"What is electricity?"—and proceed to the question.

Question 1. What is meant when a person talks about electricity?

Answer. There are certain effects which we believe to be due to electricity, so that when a person observes any one of these things, he at once declares that there is electricity present.

Question 2. What are some of these effects?

Answer. Lightning during a thunder storm. Lighting gas with a spark from the finger tip.

Question 3. Are these effects due to electricity?

Answer. Yes, but by a kind which is different enough from other electricity to be called *Static Electricity.*

Question 4. Why is it called static electricity?

Answer. Because a quantity of this kind of electricity will remain on a body provided it is hung up by a dry silk thread. This electricity is at rest or *stands still.* Static means standing.

Question 5. What other effects are due to electricity?

Answer. Ringing of an electric bell. Operation of an electric motor.

Question 6. Are these effects due to static electricity?

Answer. No, the bell and motor are operated by *Dynamic Electricity.*

Question 7. What is meant by dynamic electricity?

Answer. Electricity in motion, because the word dynamic means force, giving the idea of motion.

Question 8. What is meant by a *current* of electricity?

Answer. Dynamic electricity is usually referred to as a current of electricity.

Question 9. Are there any other effects said to be due to electricity?

Answer. Yes; the working of a wireless telegraphy instrument.

Question 10. What kind of electricity operates this instrument?

Answer. Electrical waves.

Question 11. Are there still other kinds of electricity?

Answer. Practically no. All the effects we observe may be explained as being caused by either static electricity, a current of electricity or electrical waves.

Question 12. What is static electricity?

Answer. It is electricity at rest.

Question 13. What is current electricity?

Answer. It is electricity in motion along a conductor.

Question 14. What are electrical waves?

Answer. They are electricity moving through the air, no conductor being required.

Question 15. Does the word electricity in the last three answers mean the same thing in each?

Answer. Yes; in each case it is electricity, either at rest, moving along a wire, or moving through the air without a wire.

Question 16. Give an example of static electricity.

Answer. If a brass ball be suspended by a silk thread and touched to one knob of an electrical machine (see Lesson 6) and then removed, it will be covered with a charge (see Lesson 2) of electricity. This electricity will be at rest and so is called a charge of static electricity.

Question 17. Give an example of a current of electricity.

Answer. If quantities of electricity are supplied at the end of a metal wire, they will quickly flow to the other end. Here the electricity is in motion and a current of electricity is flowing.

Question 18. Give an example of electrical waves.

Answer. If electricity is forced by a high pressure as in an electric machine or in an induction coil (see Lesson 27) to jump a spark across an air space, while doing so it will send out in every direction a series of electrical waves which will travel long distances without the aid of wires.

Question 19. What are some of the common effects of current electricity?

Answer. Heat, light, magnetism, metal plating and refining, and medical effects.

Question 20. Explain about the heat effect.

Answer. If large quantities of electricity are forced through a conductor in a short time the wire is *heated.* The poorer the conductor the more heat is produced.

Question 21. Is there always some heat produced?

Answer. Yes. Electricity cannot flow through a conductor without producing some heat.

Question 22. Are the wires in a building heated, while carrying electricity?

Answer. Yes; but the wire is large compared with the current carried; the material is copper, a good conductor, so that the heating is too small to be detected by feeling the wire.

Question 23. Does electricity produce light?

Answer. Yes. The heat produced in a very poor conductor by the current may be so great as to burn the conductor and the flame gives light; or it may make the conductor white or yellow hot, thus giving light.

The arc lamp gives light from flame and white hot carbon, while the incandescent lamp has no flame only the yellow hot carbon.

Question 24. Does electricity produce magnetism?

Answer. Yes. Electricity in motion will always affect the needle of a compass, usually pulling it aside from the north and south line, and keeping it out. This is described as "deflecting the needle" and whenever the "magnetic needle" is spoken of we mean a magnet of small weight and fairly long, pivoted so as to move freely in a horizontal direction. We speak of this effect as *electro-magnetism.*

Question 25. How does electricity plate metal?

Answer. Electricity in passing through solutions of chemicals takes the metal out of the solution and turns it into the solid form, thus making a layer of metal on the object placed in the solution. (See Lesson 17.)

Question 26. How does electricity refine metals?

Answer. If a lot of metals and other chemicals are in a solution, by passing electricity through the solution the metals will be solidified and may be removed while the other chemicals remain dissolved in the solution.

Question 27. What are the medical effects of electricity?

Answer. They are not well understood; but the passage of current through the body seems to have a curative effect on some diseases.

INTRODUCTION TO STATIC ELECTRICITY.

Static electricity is of importance to the railroad man in many ways.

In power houses and machine shops the belts often produce static electricity so that a person going near or under them will receive a rather unpleasant shock.

A locomotive blowing off steam through the safety valve becomes electrified but the charge is much too small to give any one a shock.

Lightning is static electricity and consists of such large charges that electrical machinery is usually badly damaged if lightning passes through it.

The telegraph, telephone and signal circuits, the power lines, and all buildings into which wires enter must be protected by lightning arresters.

Motor cars and electrical locomotives must be equipped with lightning arresters to protect their wiring, apparatus and motors.

A great many of the cables distributing electricity, especially at large railroad terminals, or along the right of way in the city limits are carried in conduits underground. To protect them from moisture they are covered with lead. This lead sheathing often collects electricity and heavy static discharges take place.

The discharge may injure instruments and apparatus connected to the cables or may even injure the power house or line men while handling the cables or switches attached to them.

A proper arrangement of lightning arresters and static dischargers will prevent this.

It will be seen that a thorough understanding of static electricity is a good thing for a railroad man.

There are three pieces of apparatus which are easily made, and the use of which will help one to readily understand the action of static electricity.

They are the Electrophorous, to produce static electricity; the Leyden Jar, to store electric charges in; and the Electroscope, to detect the presence of an electric charge and its polarity.

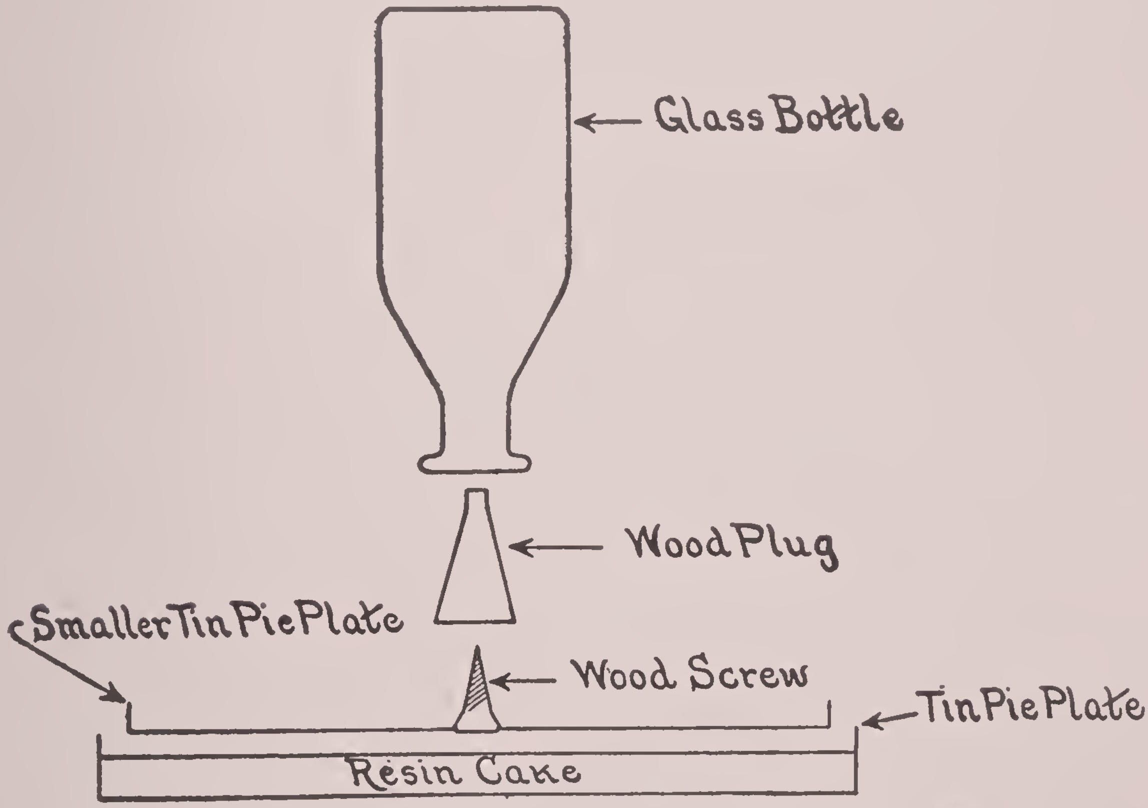

Fig. 1. Construction of an Electrophorous.

THE ELECTROPHOROUS.

Melt a mixture of two-thirds rosin and one-third gum shellac or some common red sealing wax,* by setting the dish on hot water. This is to avoid the danger of its catching fire.

---

* Sealing wax is a mixture of rosin or other resins with vermilion or some other powdered color.

Pour the melted stuff into a large tin pie plate and allow to cool into a solid cake. Slow cooling will prevent cracks, but they really do no harm.

Get a tin pie plate or tin layer cake pan a little smaller in diameter than the resin* cake. Make a wood cone. Screw a large flat head wood screw into the thick end of cone, and then solder it to the tin plate. Fasten it to the inside of bottom of plate.

Whittle the small end of the cone to a driving fit to the neck of a small glass bottle. Press the bottle on gently but firmly.

We now have a glass-handled tin dish to rest on the resin cake, touching it all over, but the two tin plates not touching anywhere.

A piece of flannel or woolen cloth is needed for a rubber.

LEYDEN JAR.

A large plain beaker should be purchased from a chemists' or druggists' supply house. The "plain" means that there is no lip on the edge. It should be large enough to hold a quart and a half of water. It will be a very thin glass and must be handled carefully to avoid breaking.

Cut tinfoil to fit the inside and outside of the bottom and dry the beaker over a stove or radiator. While dry and warm paste the tinfoil on. Warm it again and paste tinfoil over the outside up to about two-thirds its height. Let the side foil lap over the bottom foil.

---

* Resin means any gum that flows from a tree as a sticky liquid and hardens on contact with air. Gum arabic and gum shellac are resins. Rosin is a resin from a pine tree. It is left in the bottom of the stills when the spirits of turpentine are boiled off.

Cut a piece to fit the inside and roll it around a pencil. Coat the inside with paste to about two-thirds its height with paste or mucilage and stick one end of the tinfoil down. Unwind the foil from the pencil and press it down on paste with fingers or another pencil.

If the side and bottom foils do not connect, paste a strip across the seam.

Take a thin board larger than the mouth of the beaker and dry over a stove and shellac varnish it while hot.

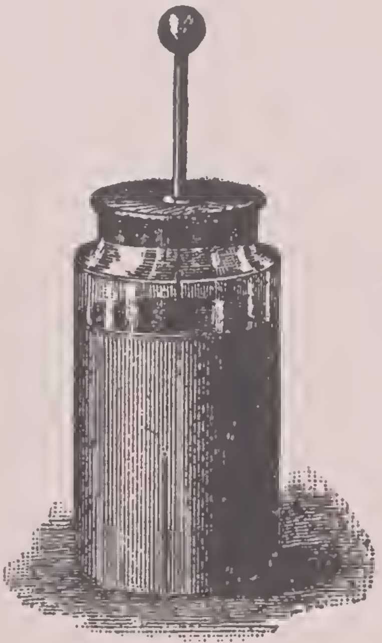

Fig. 2. Leyden Jar.

Warm the beaker and while warm and dry shellac all the glass not covered with foil.

Drill a small hole in the board and insert a short metal rod. Fit to its lower end a piece of chain long enough to touch the foil on the bottom of beaker, when the board rests on its top. Fit the upper end with a metal ball. Any size, solid or hollow makes no difference.

Put a circle of shellac varnish on the under side of board and lay board on beaker so that chain touches bottom.

When shellac dries the board will stick and keep inside of jar dry.

DISCHARGER FOR LEYDEN JAR.

Bend a piece of wire like this⏟ and stick the doubled part in a cork, put cork in a glass bottle and the result is as good as Fig. 3.

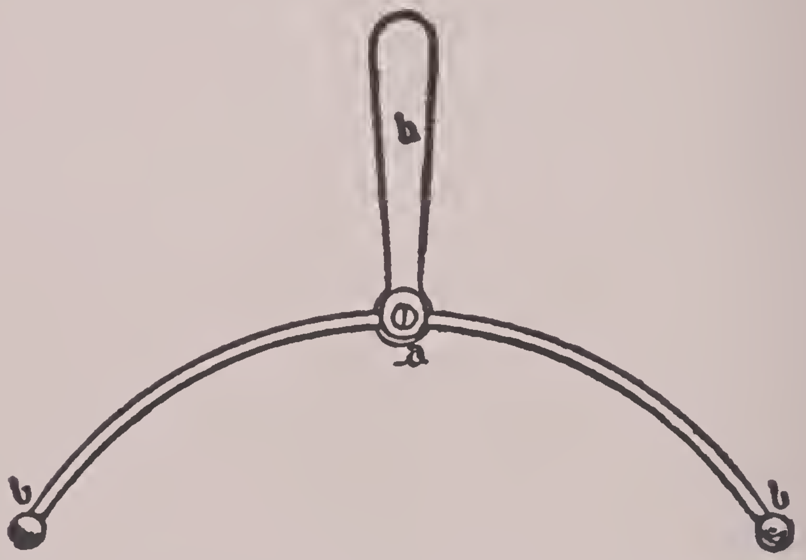

Fig. 3. Discharger or Discharging Tongs for Leyden Jar.

ELECTROSCOPE.

A wide-mouthed fruit jar is taken and a cork or wood stopper made to a loose fit.

Drill a hole through the stopper and insert a glass tube about four inches long projecting equally on both sides.

Take a small metal rod or heavy wire which will go through the glass tube and hammer one end flat for about half an inch from the end. The thinner and flatter it is made the better.

Insert wire in tube so that the flattened end is about one-third the way down the jar when cork is in place. Cut off surplus wire at other end, leaving about half an inch projecting from the glass tube.

Fix a small metal ball or plate on end of rod and let it drop down and rest on the end of glass tube.

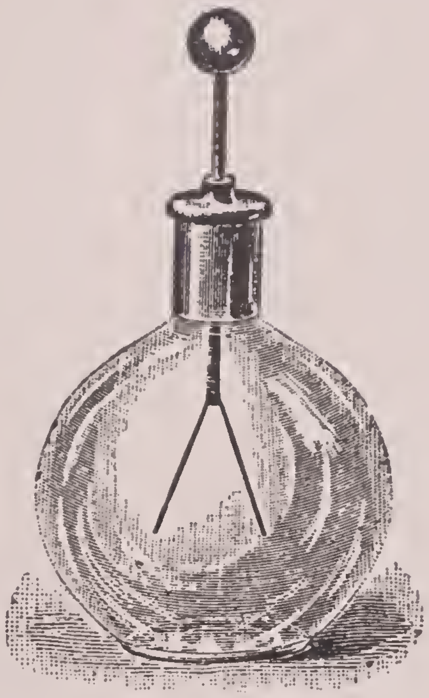

Fig. 4. Gold Leaf Electroscope.

Hold ball up against tube and turn it upside down, pouring shellac varnish into the tube till it is filled. Give the cork a coat of shellac* also.

When dry the metal rod will be cemented in the tube and the tube into the cork.

Give outside of glass rod, the cork, the neck of bottle inside and out two coats of shellac, allowing time for perfect drying between coats.

---

* A pure shellac varnish is meant, made by dissolving or "cutting," as it is called, flakes of gum shellac in alcohol. Wood or grain alcohol are equally good. Orange or brown shellac refer to the color of gum. Either will do.

The cork will now be a good tight fit.

Scrape any shellac off the flattened end of the rod and paste on two strips of gold leaf, silver leaf, dutch metal or aluminum foil; as broad as the flat end itself is wide and long enough so as to just not hit the sides of the jar if they should stand out straight apart.

Cover the bottom of the jar an inch deep with *fresh* dry calcium chloride. Buy it the day you are going to put it in jar.

Give a last coat of shellac to the outside edge of the cork and putting it in jar press down firmly, seeing that the rod with its foil leaves hangs straight.

LESSON 2.

STATIC ELECTRICITY.

Question 1. What is static electricity?

Answer. I think it is a very small quantity of electricity at a very great pressure.

Question 2. Why do you think the quantity is small?

Answer. Because we cannot get any steady power out of static electricity.

Question 3. Lightning often does considerable damage. How do you account for that?

Answer. The damage done by lightning is like a blow or an explosion, and seems to be the result of great pressure.

Question 4. A static machine gives steady power, *i. e.*, a steady stream of sparks.

Answer. No, it doesn't. The sparks follow each other rapidly but are really intermittent. There is more time between sparks than the time of a single spark.

Question 5. Why do you think it has such a great pressure?

Answer. Because it will jump across distances which current electricity will not.

In all that we see of static electricity we are constantly reminded of the fact that it possesses a power to escape which enables it to cross a considerable space of one of the best insulators known—dry air. This must mean that static electricity is at a high pressure.

Question 6. Make this clearer.

Answer. A switch in an electric circuit can be almost closed and yet no current will pass till the switch is closed. Static electricity would have jumped across when the opening between the switch blades became small.

Question 7. Mention some easy ways of producing static electricity.

Answer. 1. If you will rub a fountain pen on your coat sleeve it will attract small pieces of paper.

2. A piece of glass rubbed with a silk necktie will do the same.

3. A spark will be produced by shuffling your feet along the carpet and then touching a gas jet. This is in miniature the same effect as lightning during a thunder shower.

Question 8. Are there still other ways to produce static electricity?

Answer. Yes. 1. *Friction* between two different substances will always produce electricity unless the dampness is excessive. A leather belt on a rotating pulley will become charged and give you a severe shock if you walk under it.

2. *Percussion.* A violent blow struck by one substance on another produces positive and negative charges.

3. *Breakage.* Tear a playing or a visiting card, or even a linen paper shipping tag suddenly across, and you will charge the two pieces. Crunching a lump of sugar quickly between the teeth does the same. Split a sheet of mica with a sudden motion and you will also charge the pieces.

Any of these tests done in a very dark room will show faint sparks. The hard rubber slides of the plate holder of a camera, if pulled out suddenly on a dry day may make such a spark that you can hear the crackling noise above the sound made by the slide itself.

4. *Solidification.* When melted chocolate is poured into moulds, upon cooling and hardening it becomes electrified.

5. *Combustion.* The burning of a joss stick to keep away mosquitos causes it to become electrified.

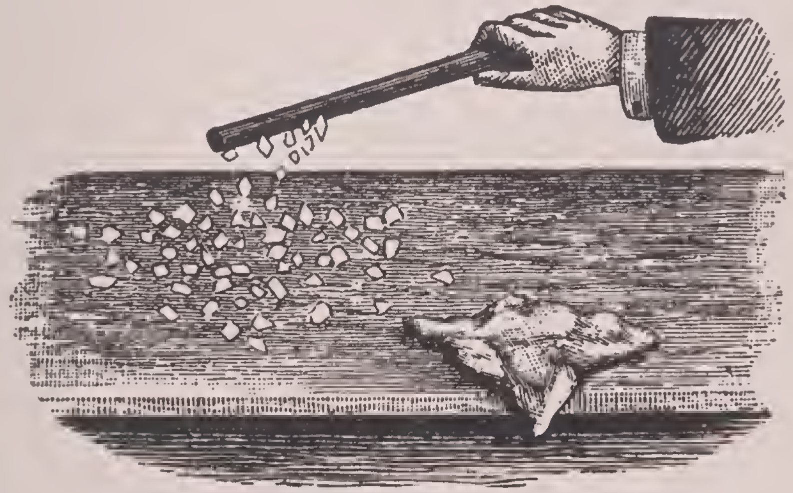

Fig. 5. Attraction due to Static Electricity.

6. *Evaporation.* The evaporation of a liquid from its surface, when that surface is roughened by waves, produces electrification. This is one of the ways that the atmosphere is kept charged relatively to the earth. In fair weather it is always positive to the earth and during rains and storms it is sometimes negative.

Question 9. Mention some other ways of showing static electricity.

Answer. Briskly rub a sheet of paper which is lying on a polished desk, with a rubber eraser, or even the hand. If the room is cool and dry the sheet will stick to the table.

If two sheets are laid down together and rubbed and both pulled away together; then when these are pulled apart they will forcibly repel each other.

Lay a glass rod on a table, one end of which extends over the edge a few inches. Attach to this a silk thread,* fastened to the lower end of which is a small ball of pith† from an elder or corn stalk.

Rub a second glass rod with a silk handkerchief and bring it near the pith ball. It will be strongly attracted, but almost immediately repelled, and it will not approach the glass rod again.

Now rub a stick of sealing wax or a piece of wood highly polished with shellac varnish, with a woolen rag or piece of flannel and bring this near the pith ball. It will be attracted and then repelled. We may repeat this attraction and repulsion as often as we please.

Question 10. I do not understand the repulsion. What causes it?

Answer. It is explained by saying that there are two kinds of static electricity or at least two states of it.

Question 11. Why does it seem that there are two kinds of static electricity?

Answer. The fact that under one set of circumstances an electrified body will be drawn to another body, and at other times will be repulsed by the same body, plainly indicates that there are two electrical states, one of attraction and the other of repulsion.

Question 12. Explain this further.

---

* A single thread drawn from a piece of embroidery silk is best because it is very light and flexible.

† Any pith will do, and it may be purchased at a drug store.

Answer. The glass rod in *A9*[*] attracted the pith ball and then repelled it. Since it acted differently towards the same charge of static electricity, there must have been a charge on the pith ball which had two conditions, one where it attracted and one where it repelled.

Question 13. How can these different states be produced or induced, as it is called?

Answer. Different electrical conditions are produced by different treatment of the bodies electrified. The glass rod rubbed by a silk handkerchief induced a condition which is unlike that induced by the flannel's friction on the sealing wax or shellac of the varnished wood.

Question 14. But this does not explain about the repulsion or the cause of it.

Answer. With the knowledge gained in this experiment and what we already know, we can find an explanation.

Lay two glass rods over the edge of the table and as far apart as possible and attach pith balls to each by silk threads.

To one present a glass rod rubbed with silk. It is first attracted and then repelled.

To the other present a stick of sealing wax that has been rubbed with flannel. It will be attracted and then repelled.

Take away the glass rod, the stick of wax, the silk and flannel to a distance. Pick up one of the glass rods and slowly bring its pith ball up towards the other. They will be attracted.

---

[*] References to Answers in same Lesson will be made in this way.

Handle the pith balls with the fingers a few seconds to dissipate their charges. Replace them as before.

Rub the glass rod with silk and present to each pith ball. They will be attracted and repelled.

Now as before bring the pith balls together and they will repel each other.

Discharge the pith balls and repeat this last part, using the sealing wax rubbed with flannel.

The balls are attracted and repelled, and when brought near together they repel each other.

We already know from *A*9 that an unelectrified body is always attracted to an electric charge before being repelled.

From these demonstrated facts we deduce the following:

Similar electric charges repel each other. Dissimilar charges attract each other. Either electrical condition may show attraction for an unelectrified body.

In short:—
Like charges repel.
Unlike charges attract.
Charges attract neutral bodies.

Question 15. This explains why the two pith balls were first attracted when one was charged by glass rod and the other by sealing wax.

It explains why they repelled each other when both were charged by glass rods.

Explain why a neutral or unelectrified body is attracted and then repelled.

Answer. We have come to the conclusion that all bodies contain equal amounts of the two kinds of static electricity.

When a body rests undisturbed the opposite qualities of the parts neutralize each other and no outside effect is observed; indeed one is tempted to say that there is no electricity in the substance.

In a similar manner drinking a glassful of a solution of caustic soda or of diluted muriatic acid would corrode the lining of your stomach, and perhaps cause death.

Mixing the two would, if the chemicals were clean and pure, and present in the right quantities, produce a large glassful of a solution of table salt in water. I would have no fear in drinking this, except for the excessive thirst sure to follow such a salty beverage.

So the question is answered in this way:—

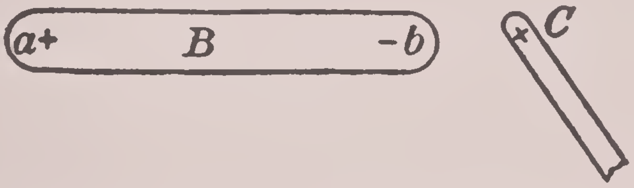

Fig. 6. State of a body B, having a charge induced in it due to the action of C.

An unelectrified pith ball is really only an uncharged one, for the two kinds of electricity are in it in equal quantities and neutralize each other.

When the glass rod charged with glass electricity was brought near the pith ball, the glass electricity of the glass rod repelled the glass electricity of the pith ball to the far side, and attracted the other kind (resinous) to the near side. See Fig. 6.

The attraction being nearer than the repulsion the whole pith ball with its separated electricities is pulled toward the glass rod.

When the pith ball gets very near the glass rod the attraction of the glass electricity on the rod actually pulls the other kind (resinous) off the pith ball, leaving only the *glass* electricity. The glass rod now repels the pith ball even more strongly than it attracted it before.

When the stick of sealing wax was presented to a pith ball the same thing is done by the *resinous* electricity of the stick, it repels the resinous kind and attracts the glass kind. The same things occur and the ball is first attracted, then repelled.

Question 16. Are these names, glass and resinous, actually used?

Answer. Vitreous and *resinous* have been used, but these names are out of date and they are now known as *positive* and *negative* electricities.

The names are usually abbreviated by using the sign + for the positive, and — for the negative.

Question 17. Then an electric charge can induce a charge in another body, that is, cause its electricities to separate, without actually touching it?

Answer. Yes, as is shown in this experiment.

A sphere of metal, or wood covered with tinfoil is mounted on an insulating stand—a wooden stand with a glass rod for its support. A second similar stand has a horizontal cylinder of conducting material, or wood covered with foil, hanging from which are double threads of silk; and to these two or three inches below the cylinder are fastened little pith balls. See Fig. 30, on page 78.

These double threads, four or five in number, are distributed along the cylinder at regular intervals.

The little cylinder, say an inch in diameter and six inches long, is now insulated from the ground.

If the sphere is now charged and brought near one end of the cylinder, each pair of pith balls will show repulsion and remain standing apart. Those at the two ends of the cylinder will show the greater repulsion and remain further apart than the pairs near its center.

If we now electrify a rubber comb or glass rod by rubbing it, we will see that, on approaching the pith balls, it will attract those at one end and repel those at the other; thus showing the ends of the cylinder to be oppositely electrified.

This proves conclusively that the approach of the charged sphere separated the two electrical conditions on the cylinders, attracting the opposite kind and repelling the same kind.

It also gives another proof that "Like charges repel," because each of the pith balls in a pair had the same kind of electricity in them, and repelled each other.

Question 18. Does the same charge always induce the same quantity of electricity?

Answer. Yes, as is shown in the following experiment.

As shown in Fig. 7, insulate a tin can by standing on a glass tumbler. Connect it to an electroscope.*

Charge a metal ball and lower into the can by a silk string, being careful not to let it touch the sides.

As the ball is lowered a charge is induced in the tin pail and the gold leaves of the electroscope diverge, showing it.

When the ball is well down into the pail the leaves will diverge no further, even if the ball is touched to the bottom.

This proves that the ball induced an *equal* and opposite charge in the pail because touching the pail with the ball added no more electricity.

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* Turn back and read description of Electroscope.

Furthermore, after the ball has touched the pail pull it out and it will be found perfectly neutral.

It was neutralized by the *equal* and opposite charge which it induced.

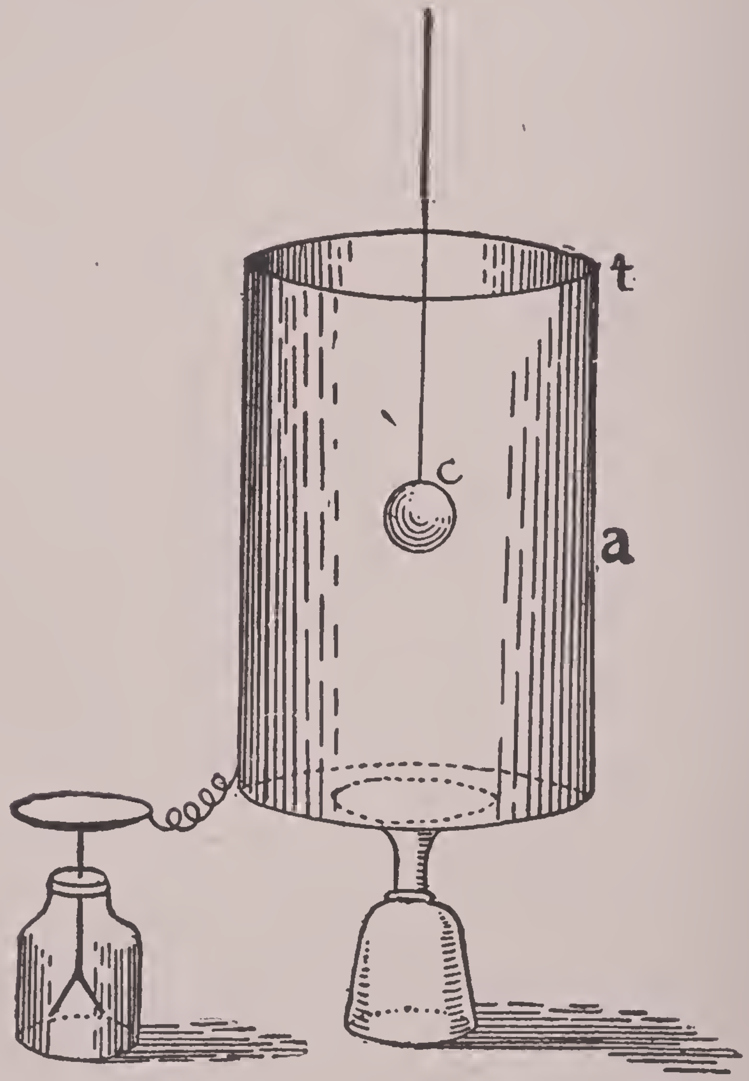

Fig. 7. Showing that the induced charge is equal and opposite to the inducing charge.

The electroscope was operated by the equal and like charge left free by the induction of the opposite charge.

Question 19. What is the usual trouble when experiments such as have been described won't work?

Answer. The things used are not perfectly dry or the air is too moist.

Question 20. What other things might cause trouble?

Answer. If the table used were set over a hot-air register, the current of hot air will carry away the electrical charges, perhaps as fast as produced.

LESSON 3.

STATIC ELECTRICITY (CONTINUED).

Question 1. Can you induce a + charge without at the same time inducing an equal — charge?

Answer. No.

Question 2. But when you rubbed the fountain pen, or the glass, or the carpet, as in *A*7, Lesson 2, only the pen, glass or body seemed to have charges.

Answer. Careful investigation will prove that the coat sleeve, necktie and the carpet under foot contain electrical charges as well as the pen, glass, and your body.

Question 3. Why *careful* investigation?

Answer. Because it is very easy to be deceived by appearances in any electrical test. Care must be taken that real effects are observed and to properly understand what we see.

Question 4. What test is usually applied to the coat sleeve, necktie and carpet to see if they are electrified, *i. e.,* if they contain a charge of static electricity?

Answer. A trial is made to see if they will attract pith balls or affect an electroscope.

Question 5. But they won't and therefore there is no charge on them.

Answer. No, not at the time they were tested, but while being rubbed or rubbing they were electrified.

Question 6. Where did the charge go?

Answer. To the ground. You see the pen and glass rod were insulators and insulated (Lesson 2) so that the electrification produced by the friction remained on them, but the coat sleeve and silk necktie were not such good insulators and were grounded, so that the charge flowed away.

Question 7. But the glass rod and silk necktie were both held in the hands. How could one be insulated and the other not?

Answer. The glass rod being fairly long its lower part acts as an insulator for the upper part. The hand, which is a good conductor, makes a contact of small area with the lower end of the glass rod. Hence the charge on the other end, say three inches away, is insulated.

The necktie makes a contact of large area with the hand and the charge being on the other side of the silk, say a few thousandths of an inch away, is not properly insulated and leaks away.

Question 8. But the charge on your body when you drew a spark from the gas jet, did not flow away.

Answer. No; because the carpet was the better grounded of the two and, moreover, the charge in the carpet, while being rubbed, was actually there and repelled a charge into the body and held it there.

After the spark to the gas jet the charge in the carpet flowed away to the ground, and any excess charge on the body also flowed away to ground.

Question 9. How can you prove that the coat sleeve and necktie had charges while being rubbed?

Answer. By mounting a piece of woolen cloth to represent the coat sleeve on a glass rod and using this rod as a handle, rub the cloth on the fountain pen.

Both the cloth and the pen will become charged, as the charge on the cloth can not flow away, it remains, can be tested and proved to exist.

The same idea may be carried out with a scrap of silk and a glass rod.

Question 10. How do you test to prove a charge exists?

Answer. By using an electroscope.

Question 11. Describe an electroscope.

Answer. As shown in Fig. 4 and in Fig. 8, it consists of a glass jar sealed up, practically moisture proof, with two leaves of metal foil hanging from a metal rod in the jar, the other end of the metal rod in the air terminates in a metal ball.

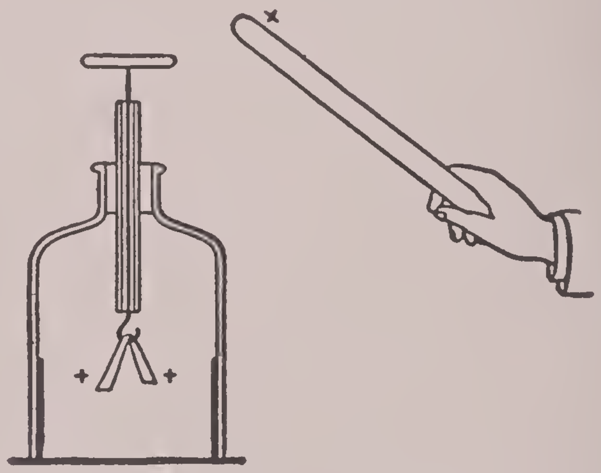

Fig. 8. Charging an Electroscope by Influence.

Two strips of foil are often pasted on the sides of the jar to discharge the foil leaves if they swing out too far.

Question 12. How do you prepare an electroscope for a test?

Answer. Rub a glass rod with a piece of silk and hold rod near the ball of the electroscope, but do not touch it. See Fig. 8. The leaves will diverge and remain apart.

While keeping the glass rod near the ball touch the ball with the other hand and remove hand. The leaves fall together. Remove the glass rod to a distance and the leaves will diverge again.

Question 13. Why does the electroscope act this way while being charged?

Answer. When the charge of + electricity on the glass rod is held near the neutral electroscope it separates the electricities and attracts the — to the ball at the top and repels all the + to the leaves at the bottom of the metal rod.

The leaves being now both positively charged repel each other and diverge.

When the ball is touched with the finger the — electricity is held "bound" by the glass rod. Any + which would run in from the earth through the hand, is kept out by the + of the glass rod, while more — is attracted from the earth. This charge combines with the + in the leaves and neutralizes so that the leaves are no longer charged. They therefore stop repelling each other and fall together.

The — in the ball is still held "bound" by the + of the glass rod and can do nothing.

The finger being removed, and then the glass rod being taken away, the — charge which was in the ball spreads all over the ball, rod and leaves.

The leaves being now each charged with — they repel each other and diverge.

Notice that the final charge of the electroscope is opposite to the charge of the charging body.

Question 14. How do you test for a charge?

Answer. Bring the body on which a charge is suspected near the ball and if the leaves diverge further or fall together there is a charge on the body; if they are not affected there is no charge on the body.

Question 15. How do you determine the kind of electricity on the body?

Answer. If the leaves diverge further when a body is brought near the ball its charge is the same kind as is in the electroscope, if they come together it is charged with the opposite kind.

Question 16. What electricity is the electroscope usually charged with?

Answer. Usually a glass rod carrying a + charge is used, which induces a — charge in the electroscope.

Then a further divergence of the leaves means a — and a collapse of the leaves means a + charge on the tested body.

Question 17. What is the general rule for determining the kind of electricity with an electroscope?

Answer. Collapse of leaves means same kind of electricity as was used to charge the electroscope. Divergence of leaves means different kind.

Question 18. How can you charge any body so as to have only one kind of electricity in it?

Answer. By inducing a separation of the electricities by means of a charged body and then drawing off the "free" charge by touching the body with the finger.

Question 19. What does *bound* and *free* charges mean?

Answer. A *bound* charge means a charge which is attracted and held by a charge of the opposite kind.

Touching a body with a bound charge has no effect upon it, because it is not free to neutralize with any electricity that might flow in, nor can it flow away, since it is held by the other charge.

A *free* charge is a charge which is under no influence or under the influence of a charge of the same kind.

When a body is touched the free charge is either neutralized by the inflowing charge or flows away itself to the earth. Probably both of these actions take place.

Question 20. What is the best way to get a fairly large charge of electricity?

Answer. By the Electrophorous.

Question 21. Describe the Electrophorous.

Answer. As shown in Figs. 1 and 9 it consists of a plate of resin resting on a metal plate, and a second metal plate with an insulated handle, rests on the resin.

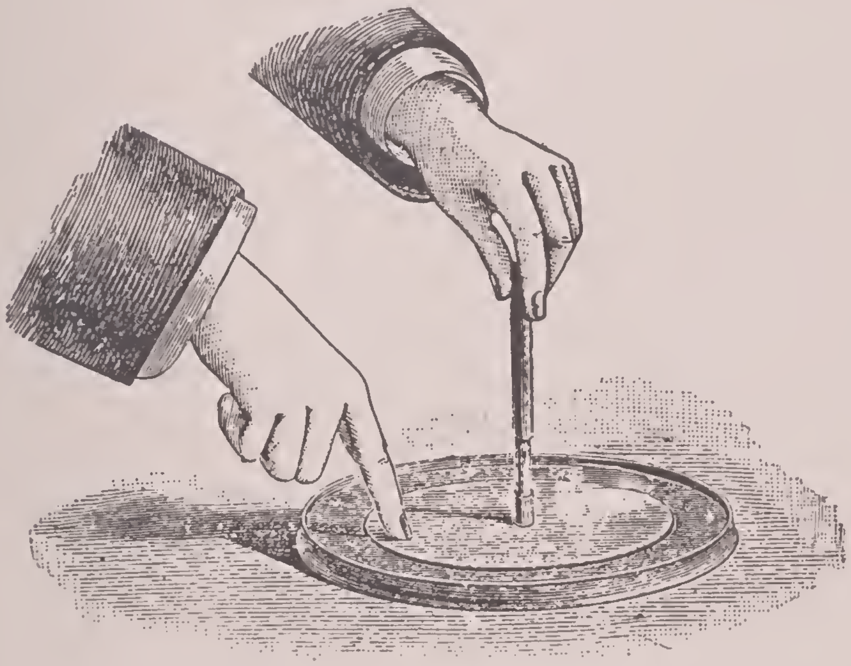

Fig. 9. Using an electrophorous.

Question 22. How is the Electrophorous used?

Answer. The upper plate or cover is removed and the cake of resin is rubbed or beaten with a piece of warm dry flannel or cat's skin.

The cover is then taken up by the glass handle and placed lightly on the cake. With thumb and forefinger touch the metal plate containing the resin cake and the metal cover at the same time.

Lift the cover off by the handle and it will be charged.

Question 23. How can you prove it?

Answer. By drawing a spark from it by the finger.

Question 24. Do you rub the resin cake each time you want a spark?

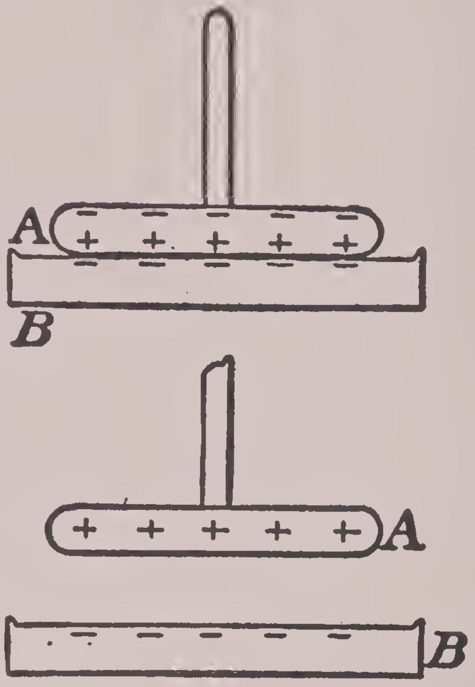

Fig. 10. The Electrical State of an Electrophorous when cover is on, and then after being touched and cover lifted.

Answer. No. The cover may be replaced, touched as before, removed, and a spark drawn, over and over again. If left after being used the charge on the cake will leak away and rubbing will be necessary.

Question 25. Explain how the Electrophorous works.

Answer. When the resinous cake is first beaten its surface is —ly electrified and the + driven into the metal pan. See Fig. 10. When the metal cover is placed lightly on the cake it does not touch at all points and is really an insulated conductor.

The — charge on the resin cake acts by influence on the cover and induces a + charge on its under side and repels the — charge to the upper side.

When the cover and the bottom pan are touched by the finger, several things happen. From the earth the resin cake attracts more + charge to the lower side of the cover and repels the — on the upper side of cover out to the earth through the finger. This gives the cover a larger + charge than before. This + charge is bound and cannot escape.

The connection of the bottom pan to earth allows its + charge to be increased, which in turn helps to "bind" the — charge on the resin.

If the cover is now lifted by the insulated handle the + charge on it spreads over it and it is charged ready to give a spark.

Question 26. Will the Electrophorous work if only the cover is touched with the finger?

Answer. Yes, but the spark is stronger when both cover and pan are touched.

Question 27. Is the original charge used up in drawing several sparks in succession?

Answer. No, because the electricity which gives the spark is really drawn from the earth each time.

Question 28. You have obtained energy without any cost, have you not? This is contrary to nature's laws.

Answer. No. The cost of the spark is the muscular effort of the first rubbing, and the subsequent touching and liftings.

Question 29. How can a larger charge be obtained?

Answer. By accumulating the small charges given by the electrophorous.

Question 30. What is used to accumulate charges?

Answer. A Leyden Jar.

Question 31. What is a Leyden Jar?

Answer. It is a glass jar lined inside and outside with tinfoil with a conductor passing through an insulated cork touching the inside foil. See Fig. 2.

Question 32. How is the Leyden jar used?

Answer. To get the best results connect the outer coating of tinfoil with a wire or chain to a gas or water pipe, thus giving a good connection with the earth.

When the cover of the electrophorous is lifted, present it to the knob of the jar and let the spark jump to it. Repeat this a dozen times, and the jar will be charged.

Question 33. How do you show this charge?

Answer. Connect the ball with the outer coating using the discharger (Fig. 3) and a heavy spark will be obtained.

Question 34. Will it be twelve times as large as the electrophorous spark?

Answer. No. It will be much larger than the electrophorous spark, but not twelve times as large, for there are leaks and other losses which will reduce its size.

Question 35. Explain the main leak.

Answer. Glass is a hygroscopic substance. This means that moisture collects on its surface very easily. A china tea cup will have a dry surface in a room, while a glass tumbler alongside of it will have a very damp surface.

The charge leaks from one coating of tin foil to the other over this film of moisture.

The shellac varnish on the glass is to prevent this film of moisture forming. It does this very well.

Question 36. What is another cause of leakage?

Answer. There is the leakage from the coatings to the air, because particles of air become electrified and are then repelled.

Question 37. Why does not all the charge leak away?

Answer. In a poorly made jar it will; but with well shellaced glass, used in a dry atmosphere the leakage is slow, and the binding influence of the inner and outer charges on each other retains the charge.

Question 38. Is there any other leakage?

Answer. Yes there is leakage through the glass. While glass is principally sand and soda yet there are other ingredients added according to the grade of glass. The cheaper kinds have accidental ingredients, really impurities, which lessen its value for electrical purposes. A general rule is that the more expensive the glass the better for electrical work.

A leyden jar to approach nearest to electrical perfection should be of glass containing no lead or other conducting material..

For simple experimenting a cheap glass such as bottles or fruit jars are made of will do.

In such cases it is absolutely necessary to coat the glass with shellac varnish before putting on the tin foil.

Question 39. How can a larger spark be obtained?

Answer. By accumulating more electrophorous sparks.

Question 40. Is there any limit to the size?

Answer. Yes; in time the pressure of the charge to escape will be so great that the charge will either leak as fast as it is added to or the pressure will flash a spark over the edge of the glass.

Question 41. Will a larger leyden jar give a larger spark?

Answer. Yes, a jar large enough to have twice the amount of tin foil put on will give twice as large a spark.

Question 42. What do you mean by "twice as large a spark?"

Answer. Either twice as long a spark, the same length but twice as thick or some combination like this. Twice as long and twice as thick, would be a spark four times as large.

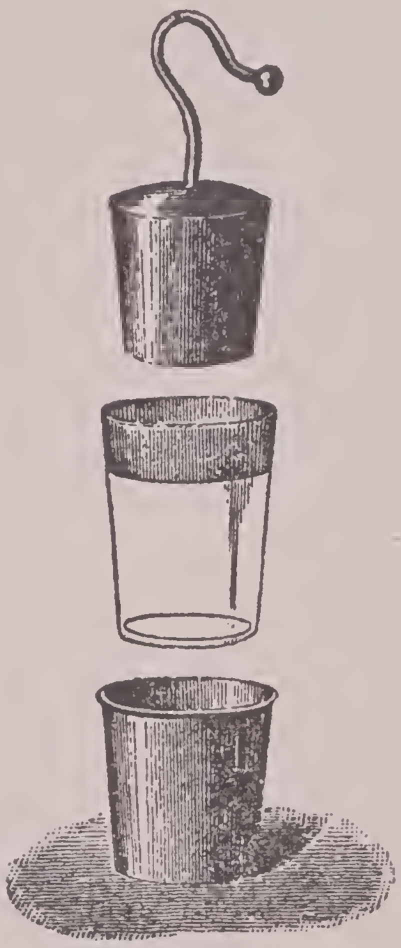

Fig. 11. A Leyden Jar with Removable Coatings.

Question 43. Can several leyden jars be used at once?

Answer. Yes, stand them all on a sheet of metal, and connect all the knobs together with a piece of wire. This is now the same as one big jar. Fig. 27, page 75.

Question 44. How does a leyden jar work?

Answer. The theory of the leyden jar is best explained through the aid of an experiment, which requires a peculiar form of jar, but which is easily constructed.

Take a large glass tumbler, and varnish inside and out with shellac. Arrange the inner and outer coatings so as to be removable. Fig. 11 shows one where the coatings have been made thick and stiff to facilitate their removal.

A jar may be arranged more simply by attaching a ball of tin foil refuse to the lower end of the rod so that it will rest on the bottom of the jar and form the inner coating.

For the outer coating thin sheet metal or foil may be wrapped around the jar and tied with thread.

Place a board on several glass tumblers thus making an insulated stand. Place jar on stand.

Charge the jar. Lift out the rod and inner coating—being careful not to come within sparking distance of the outer coating—and place on board. Now lift the jar from the outer coating and place on board.

In each of these contacts a very slight shock will be received by the hand.

A test of the two coatings will show that they are neutral, as is natural since any charge on them would be neutralized by touching them by the hand.

Replace the jar in its coating, and put the inner coating in place. Discharge the jar by making contact between the coatings, and it will be seen that there is nearly as much electricity in the jar now as if the coatings had not been disturbed.

It is evident then that when the inner and outer coatings were removed that the electricity in the jar was not disturbed, for the outer charge remained bound after the inner coating was removed.

We explain this by saying that the charges are really on the inner and outer surfaces of the glass and that the tin foil is only a means of getting the charge to the glass.

When we took the jar apart the slight shocks were due to leaks, but the main charges stayed on the glass.

Question 45. Could the glass be discharged while out of its coatings?

Answer. Yes, by connecting inside and outside by a broad strip of tin foil. Doing this as if you were trying to wipe off the charge.

Holding the glass under a tap and running water over it will instantly discharge it.

Question 46. Will you get a spark by this discharge?

Answer. It depends. If you make a broad contact at first you will not, because the charge flows over such a large surface. If you get a spark it is a feeble one for the glass being an insulator it cannot rush to the point of discharge quickly enough to make a heavy spark.

Question 47. Do the foil coatings enable a spark to be obtained?

Answer. Yes, without them the discharge is a fast leak; with them the charge can rush through the conducting coatings to the discharging tongs and the discharge is a quick snappy one.

Question 48. Why will a leyden jar give a second spark a few seconds after being discharged?

Answer. We believe that the charges penetrate the glass to a certain extent and the first spark discharges all the charge on the surface of the glass, but it is over before the charge which soaked into the glass has time to escape.

The second time the jar is discharged we allow this residual charge, which has come back to the surface, a chance to escape. This second spark is very much weaker than the first one.

Question 49. What is meant by saying that the discharge of a leyden jar is *oscillatory?*

Answer. In the first place the spark or discharge is not instantaneous although very quick. This can be shown by flashing a spark at some gunpowder, it will not explode, but insert a piece of wet string about a foot long in the wire leading up to the spark gap and the spark will be forced to travel slower. It will then in its slower movement heat up the gunpowder and ignite it.

But this is not all. The spark as we call it, whether it be a fast or slow one, is not a single spark, but a series of sparks.

There are always a great number of them jumping in alternate directions, each weaker than the last until they are too feeble to jump across the gap. The electricity which forms the spark *surges* or *oscillates* between the sparking points.

The sudden emptying of a barrel of water in a tank will cause the water in tank to surge back and forth, in waves, each successive one being smaller, until the whole mass settles down and becomes quiet.

The action of a pendulum set in motion and gradually coming to rest illustrates the action also, provided you imagine the pendulum moving at a furious speed.

LESSON 4.

CONDENSERS.

Question 1. Why is a leyden jar often referred to as a condenser?

Answer. Because that is the general name for apparatus designed to collect charges of electricity.

Question 2. What is a condenser?

Answer. A condenser consists of two metal plates separated by an insulator.

Question 3. What is the *dielectric* of a condenser?

Answer. It is the special name given to the insulator of a condenser.

Question 4. Explain the action of a condenser.

Answer. If a pane of glass be set on edge and a piece of tin foil pasted on one side it will have a certain capacity for electricity, but if another piece is pasted on the other side and charged with the opposite kind of electricity then the first piece will have a greater capacity. It is as if this arrangement could condense electricity, that is get more in the same space.

Question 5. What is meant by capacity?

Answer. A piece of tin foil could have its charge increased until the leakage equalled the amount put on, then we might say that it was full, and that the amount on it was its capacity. Since this amount would vary with the dampness of the air, the temperature of the tin foil, and the rate at which you added electricity, a more definite way has been adopted to define *Capacity.*

A certain pressure is called a volt. We apply electricity to the condenser increasing the pressure until it becomes one volt, then we say the condenser is full enough and the charge then in it is said to be the *capacity* of the condenser.

Question 6. On what does the capacity of a condenser depend?

Answer. On three things:—

1. The area of the metal part.
2. The thinness of the dielectric.
3. The kind of dielectric.

Question 7. Does not the kind of metal used or its thickness affect the capacity?

Answer. No, only the area. The greater the area the greater the capacity.

Question 8. Why is it that the thinness of the dielectric affects the capacity?

Answer. Because the thinner the dielectric the nearer the metal portions are to each other and so the electrical action between the charges is greater.

Question 9. Why should the material used as a dielectric affect the capacity?

Answer. Exactly why is not known, but it is a fact that the electric action takes place through the same thickness of different materials with more or less strength according to the material.

Question 10. What is the metal portion of a condenser usually made of?

Answer. It is always made of tin foil, for it is thin and hence light in weight for large areas.

Question 11. What is used generally as a dielectric?

Answer. For condensers used in commercial work, paper soaked in paraffin is used while for standard condensers used in laboratories to test others, mica split into thin sheets is used.

Question 12. What are the advantages of the paper condensers, as they are called?

Answer. They are cheap to make, light in weight and good enough for many purposes.

Question 13. What are the objections to paper condensers?

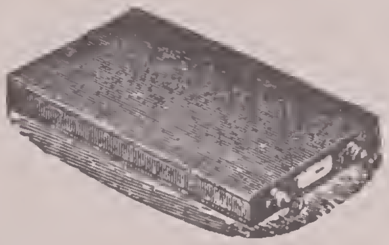

Fig. 12. Paper Condenser.

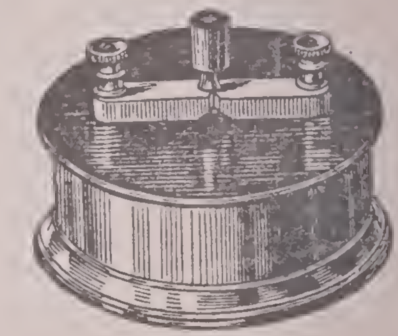

Fig. 13. Mica Condenser.

Answer. They cannot hold a charge as long as a mica condenser, as the insulation is not so good. They leak considerably, that is the charge leaks from foil to foil, thus discharging the condenser. If rapidly charged and discharged the paraffin is heated and may soften or even melt.

Question 14. What are the advantages of the mica condensers?

Answer. They hold their charge without leaking for a long time, rapid charge and discharge does not heat them much, and even so mica is not affected by temperatures at which paraffin would liquefy. Their capacity is great, so a mica condenser is smaller than a paper one of the same capacity.

Question 15. What are the objections to mica condensers?

Answer. They are expensive, and while small in size are very heavy.

Question 16. How would the capacities of three similar condensers of mica, paraffined paper, and glass compare?

Answer. Selecting a condenser with air for a dielectric as a standard because it is the poorest condenser of all, the mica is the best being six to eight times as good as the air condenser. The glass one would be three times as good as the air one. The paraffined paper dielectric makes the poorest condenser being only twice as good as air.

It must be remembered that some mica, such as used in oil and gas stoves is worthless as a dielectric, as it has fine lines of metal running through it, and hence is a conductor.

Some grades of glass are also almost useless for a condenser.

Question 17. What is the standard capacity?

Answer. The scientists' standard was a metal sphere of 1 cm * radius perfectly isolated and insulated.

This capacity is so absurdly large that all electricians used as a standard a unit which is 1-900000 of the other.

This unit is called a microfarad (abbreviated *m. f.*) and is now used by scientists and electricians.

Question 18. How big a condenser is a microfarad?

Answer. A mica condenser containing 3600 square inches of tin foil.

Question 19. How is a paper condenser made?

---

* The centimeter (abbreviated *cm,*) is the 1/100 part of the French standard length called the meter. A meter is approximately 39.3 inches, so a centimeter is about 0.4 inches and there are roughly 2½ cm. to one inch.

Answer. The finest and thinnest linen paper is examined to be sure that it is free from small holes, the tiniest hole causes a sheet to be rejected.

They are then dried and warmed, dipped in a bath of melted paraffin, from which all water has been extracted, and allowed to drain and cool.

A pile is made of alternate sheets of tin foil and paper. The papers are placed with all their edges even, but each alternate foil projects on the same side of the pile. The first, third, fifth foils project to the right and all the even numbered foils project to the left.

Each set are all connected together, and the whole mass clamped tightly and put in a case for protection.

Binding posts are connected to each set of foils.

Question 20. What name is given to the quality of a dielectric?

Answer. Dielectric capacity or *specific inductive capacity* is the name used.

Question 21. What is the standard of dielectric capacity?

Answer. Perfectly dry air at normal pressure and temperature of 0° Centigrade* is said to have a dielectric capacity of 1.

Question 22. How is the dielectric capacity of materials measured?

Answer. By comparing them with air. Air has the least value as a dielectric, so other materials are said to as is needed these equal divisions are carried. If carried below 0, we read the temperatures as minus 1, minus 2, or 1 below zero, 2 below zero; and we write them —1, —2.

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* The Fahrenheit thermometer is the standard throughout the business and social life of the United States and Great Britain.

The temperature of freezing water is called 32 degrees and that of boiling water 212 degrees. The range between these temperatures is divided into 180 equal parts, numbered consecutively from 33 to 211, and as far below 32 and above 212

In scientific work all over the world, the thermometers are marked differently.

The freezing point of water is marked 0 and the boiling point of water 100, and the space between into 100 equal parts. These divisions are carried down below the zero and above the 100 mark.

This thermometer was introduced by a man named Celcius, but is named Centigrade because it has 100 steps between freezing and boiling points. (Centum is 100 in Latin and gradus means step.)

Since 100° Cent. = 212° Fah.
and 0° Cent. = 32° Fah.
then 100° Cent. = 180° Fah.
and 1 Cent. degree = 1.8 Fah. degree.

To change Centigrade readings to Fahrenheit:

Multiply by 1.8 and add 32.

Ex.—A room whose temperature is 21° C. is 69°.2 Fah.

$21 \times 1.8 = 37.2 + 32 = 69.2.$

To change from Fahrenheit to Centigrade:

Subtract 32. Multiply by 5 and divide by 9.

A room which is 70° Fah. is also 21° (approx.) Cent.

$70 - 32 = 38$

$38 \times 5 = 190$ $190 \div 9 = 21°.1$ Cent.

The mark ° means degree and the abbreviation C. or Fah. after it tells the kind of degree.

When a decimal fraction is written it is always thus: 7°.2, so that should the decimal point be forgotten or not written clearly it can not be mistaken for 72°.

Also when a fraction of a degree is written it is thus: 0°.5, so that we may know that it is five-tenths of a degree and not 5 degrees even if decimal point is not there.

The 0 is placed there to show that it really is five-tenths and that some figure has not been forgotten.

It might be that 2°.5 was meant and °.5 written by an omission. By writing 0°.5 the writer shows he has not forgotten a figure.

have a dielectric capacity of 2 or 3 as the case may be, if they are twice or three times as good as air, when used in a condenser.

Question 23. Has capacity any effect on commercial work?

Answer. Yes a great deal.

Question 24. Mention some effects.

Answer. In sending alternating currents through a long line the presence of capacity may help to neutralize some of the bad effects of coils of wire in the circuit.*

Also in telephone lines the presence of much capacity is exceedingly bad, making the transmission of the voice difficult and producing a tinny tone.

For this reason paper insulation is used in telephone cables, rather than rubber. The latter has a much higher dielectric capacity, making the cable a better condenser and a worse telephone line.

Question 25. Are there any other effects?

Answer. Yes. The capacity of long telegraph lines makes signalling very slow; for the line has to be filled up each time before the signal will be transmitted, and it has to empty itself before the next signal can begin.

Long submarine cables are especially troubled this way. The wire inside and the water outside are the two conductors and the gutta percha† insulation is the dielectric. This makes a condenser.

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* A *circuit* is the path of the current from the battery or generator out and back again to the starting point. By *line* we often mean the same thing.

† Gutta percha is a gum something like rubber but a better insulator, less dielectric capacity, less likely to deteriorate with age, and can stand more moisture. It is injured by light, and should never be used in a light, hot, dry place. It is

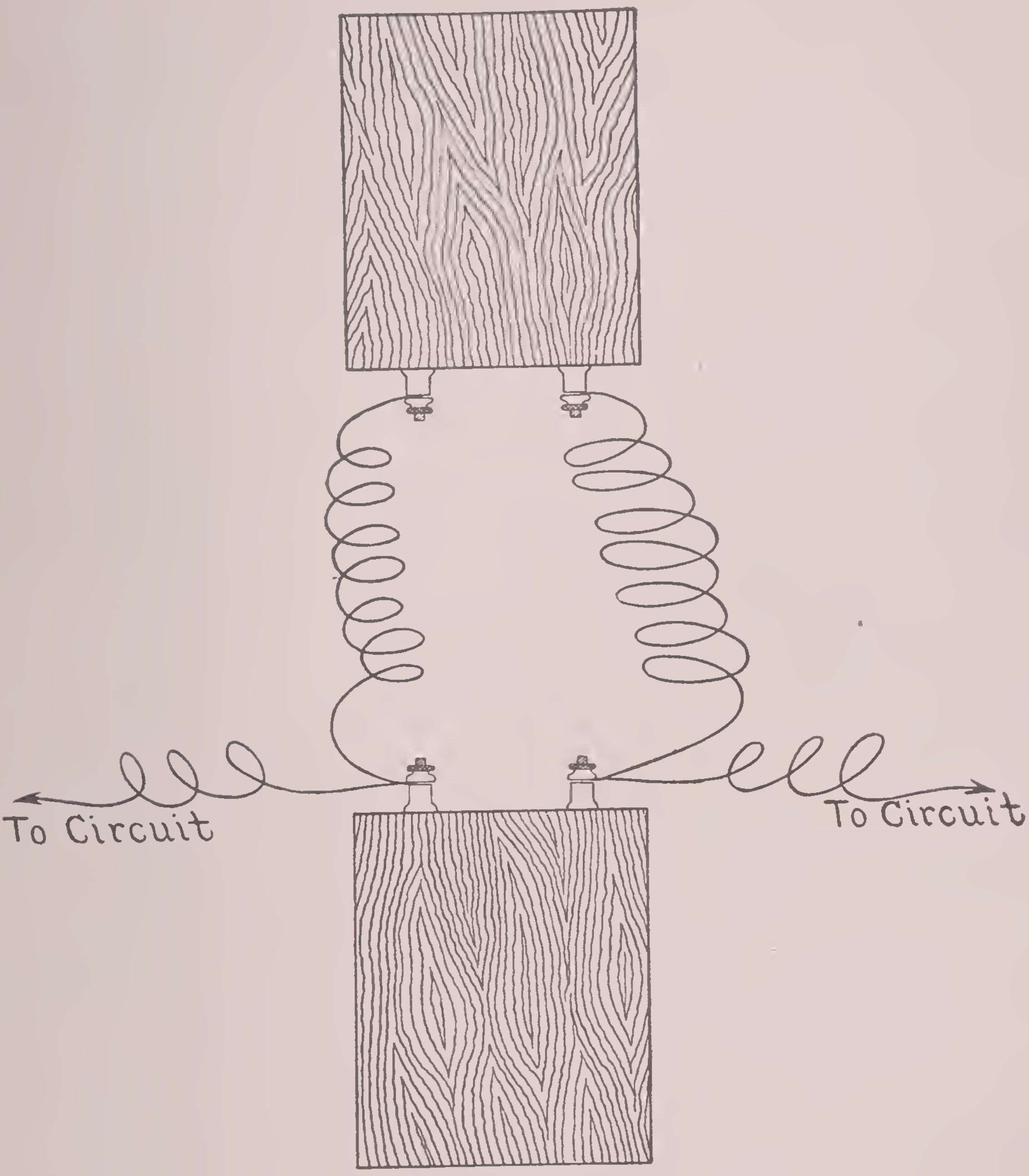

Fig. 14. Two Condensers wired so as to be in Parallel.

One of the Atlantic cables has a capacity of about 1000 m. f. (microfarads). This makes the signalling very slow and limits the amount of business that can be transacted per hour.

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easily softened by placing in hot water. It is lighter than rubber and a piece of it will usually float.

It is used chiefly as an insulator in ocean cables.

The operators can send faster than the cable can take; that is if the operators went as fast as they could, the signals would jumble up and be unintelligible at receiving end.

Question 26. How are condensers used in commercial work?

Answer. In ocean cable telegraphy a condenser is often put in at each end, which by absorbing the electricity on the opening of the circuit and giving it out on the closing of the circuit, help the battery to fill the cable on the close of the telegraph key, and help to stop the electrical flow when key is opened.

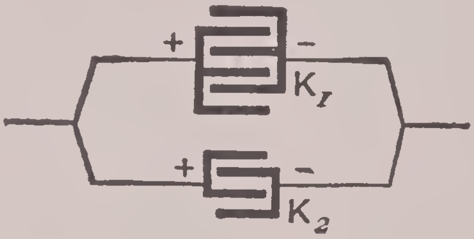


Fig. 15. Diagram of Two Condensers connected in Parallel. The black lines represent the sheets of tin foil.

In ordinary telegraphy when sending two or four messages over the same wire at the same time, an artificial line must be formed which is electrically exactly like the real line. Coils of wire give the resistance of the actual line, and condensers its capacity.

Question 27. How can two condensers be used as one large condenser?

Answer. As in Fig. 14, connect a wire from one binding post of the first condenser to either binding post of the other condenser. Connect the other two posts by a wire. Connect the wires of the circuit, one to each of the wires joining the condensers.

A convenient way of attaching the wires of the circuit is to loosen up both binding posts on the one condenser; slip the circuit wires under and tighten up again.

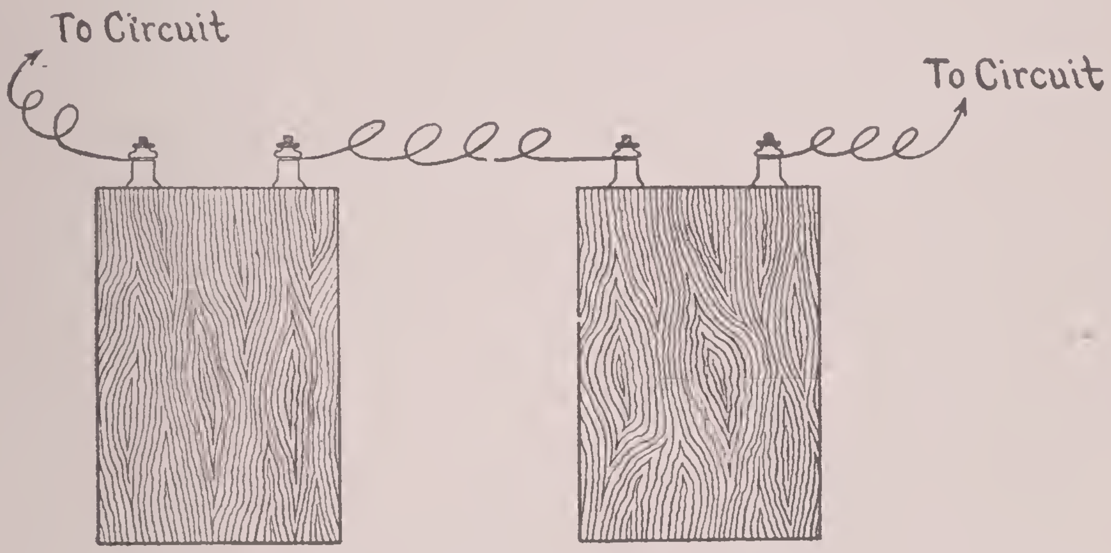


Fig. 16. Two Condensers in Series.

Question 28. What is the actual capacity of two condensers connected in parallel?

Answer. The capacity of this arrangement is the *sum of the two capacities.*

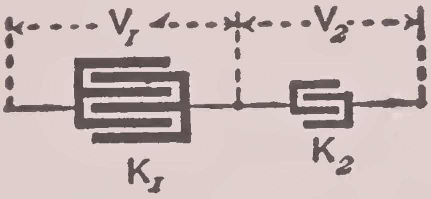


Fig. 17. Diagram of Two Condensers in Series. K_1 is supposed to have a greater capacity than K_2. The dotted lines show where to connect voltmeters V_1 & V_2 to read pressure of condensers.

Question 29. Suppose you connect the circuit (or line) through the two condensers?

Answer. If as shown in Fig. 16 you bring a line wire to one binding post of the first condenser, and the other line wire to a post of the other condenser, and join the other two posts with a wire you will have them in series.

Question 30. What is the capacity of two condensers in series?

Answer. The actual capacity of the two in series will be *the product of the two divided by their sum.*

Calling C_1 and C_2 the capacities of the condensers, the joint or combined capacity will be expressed as $\frac{C_1 \times C_2}{C_1 + C_2}$

Ex.:—A 2 m f and a 3 m f condenser are connected in series. What is capacity of combination?

$$\frac{C_1 \times C_2}{C_1 + C_2} = \frac{2 \times 3}{2+3} = \frac{6}{5} = 1.2 \text{ m f.}$$

You will notice that the capacity of the two wired up in this way is less than the capacity of either.

Question 31. Suppose you connect three condensers or even more in parallel. What is their joint capacity?

Answer. The sum of their separate capacities.

Question 32. Suppose you connect three or more condensers in series, or as it is sometimes called in *cascade.* What is their joint capacity?

Answer. Divide each separate capacity into 1 add the answers and divide this into 1. Result is joint capacity.

Suppose three condensers have capacities of ½, 3 and 5 mf.

½ into 1 goes 2 equals $\frac{30}{15}$
3 into 1 goes $\frac{1}{3}$ equals $\frac{5}{15}$
5 into 1 goes $\frac{1}{5}$ equals $\frac{3}{15}$
Sum $\frac{38}{15}$

$\frac{38}{15}$ into 1 goes $\frac{15}{38}$ times.

$\frac{15}{38}$ or 0.4 (approx) m f.

Question 33. Describe an experiment showing how a condenser works.

Answer. Suppose as in Fig. 18 we have two metal disks A and B insulated by glass supports, with a sheet of glass or mica between them.

Let B be connected by a wire to the knob of an electric machine and let A be joined to a gas or water pipe by a wire; thus connecting it to ground or earth.

The + charge from machine will act by induction across the dielectric C, on A and repel + to earth, leaving the disk A — ly charged.

This — charge will react on B and draw more + from the machine.

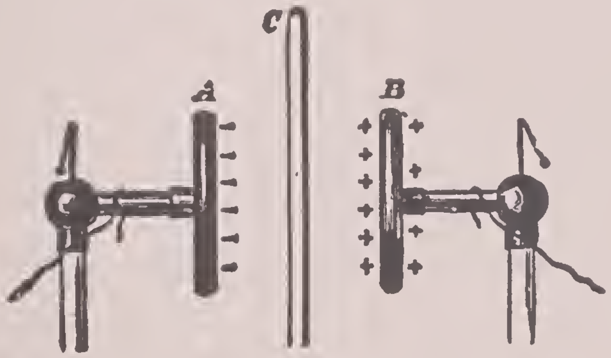


Fig. 18. A Condenser arranged so as to use different dielectrics at C, and with plates A & B movable.

The nearer A and B are together the better the induction acts and the more electricity will be condensed.

If the wires be removed from A and B and the disks drawn apart, the pith balls will fly out showing that there is more electricity "free" to act than before.

We ought not to say more electricity is present, it is simply more "free"; for the two charges will not hold each other so "bound" at the greater distance. This freed electricity spreads over the plate and balls. When the disks approach each other again this free electricity is drawn back to the plates and held bound. Hence the pith balls become discharged or nearly so and fall.

LESSON 5.

ELECTRICAL MACHINES.

Question 1. What is an electrical machine?

Answer. Used in this sense the words mean any of the machines capable of producing static electricity.

Question 2. Describe the simplest machine.

Answer. The simplest machine is a friction machine. A circular glass plate is mounted on an axle and arranged so as to be turned rapidly by belt and pulley. See Fig. 19.

At the top and bottom of plate a cushion of curled hair covered with leather is bent around so as to squeeze the plate. Light springs keep these cushions in firm contact.

At both sides of the plate is a set of spikes nearly touching the plate both on the back and the front. A conductor connects the two sets of spikes. A wire from this conductor leads to a metal knob or club which is called the prime conductor.

The two cushions are connected by a wire, and this in turn to the ground.

A silk bag or flap runs from the cushion or rubber to the spikes or comb. Both the rubber and the comb are insulated by glass supports.

The rubber has a thin layer of tallow spread on it and some powdered electrical amalgam sprinkled on. They are then pressed against the glass and the springs adjusted to keep them there.

When the plate is rapidly revolved the friction between the glass and the amalgam coated surface of the rubber produces electrification; a + charge on the glass and a — charge on the rubber.

Positive electricity flows from earth to the rubber and neutralizes its charge. In fact the ground wire keeps the rubber continually neutral.

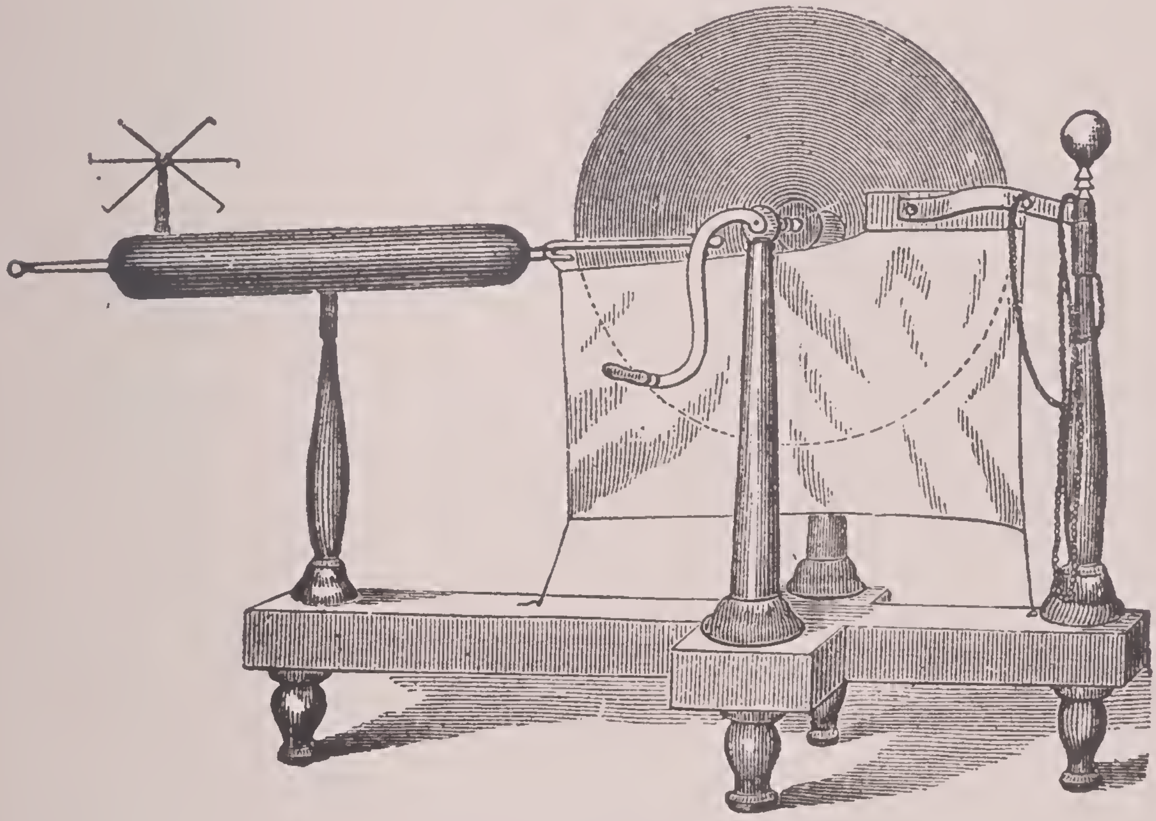


Fig. 19. Simple Electrical Machine.

The + charge is carried around on the glass in front of the comb which is connected with the prime conductor repelling a + charge to the knob of the conductor and attracting the — into the comb. The effect of the spikes is to emit a —ly charged electrical wind which neutralizes the glass plate and prepares it for the action of the next rubber and at the same time leaves the prime conductor +ly charged.

Question 3. What is electrical amalgam?

Answer. One ounce of tin and one ounce of zinc are melted together and while melted four ounces of mercury are stirred in. When cool the mass is powdered and sifted. It may be sprinkled on the rubber from a salt shaker.

Question 4. Why is this amalgam used?

Answer. It produces a better charge than any other substance and moreover, by being a conductor helps the prompt neutralization of the rubber, which also tends to make the charge on the glass plate larger.

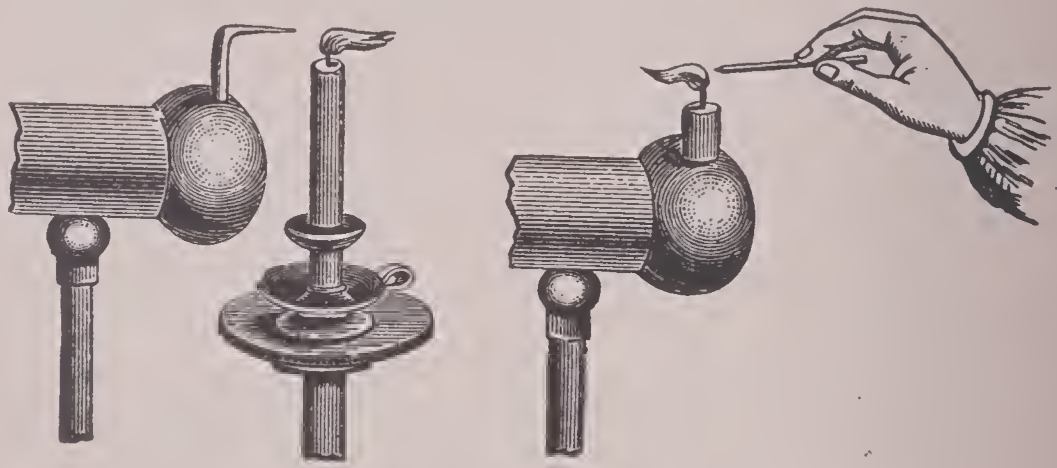


Fig. 20. Electrical Winds.

Question 5. Is the use of this amalgam necessary?

Answer. No. Powdered graphite will work very well. Simply rub it into the leather of the cushion. Of course omit the tallowing.

Question 6. What is an electrical wind?

Answer. It has been found that electricity leaks from sharp cornered bodies like a cube faster than from rounded ones like a ball. From sharp pointed bodies it leaks so fast as to actually produce a brisk air current.

If a needle be fastened to the prime conductor and a lighted candle held near the needle the wind rushing off the needle will blow the candle flame aside. See Fig. 20.

The wind can also be plainly felt by the hand.

Question 7. Why does the candle on the knob get blown in the opposite direction?

Answer. Because now the wind is caused by the opposite kind of electricity flowing off the needle to the knob.

The wind is always blowing off the point.

Question 8. What are the silk bags for?

Answer. The silk being an insulator prevents the + charge on the glass from leaking off into the air before it arrives at the comb.

It is believed by many that the air currents produced by the swiftly moving plate, electrifying the silk negatively and being a non-conductor, it is imperfectly neutralized by any ground connection that may happen to exist, so there is always a — charge on the silk to "bind" the + charge on the glass.

This action is not strong enough to interfere with the effect of the negative wind at the comb.

Question 9. Are not frictional machines generally unreliable?

Answer. Yes. Dampness and dust may prevent them from working. Glass attracts moisture so that the machines always have to be heated to dry them before use. The amalgam will need renewing before use if the machine has been standing idle for a couple of months.

Question 10. Is there another type of electrical machine more reliable?

Answer. Yes, the influence machine. These are very reliable.

Question 11. What principle do they involve?

Answer. The principle of charging induction or influence, and of doubling up charges.

Question 12. Explain what is meant by charging by influence?

Answer. A body touched while under the influence of a charge acquires a charge of the opposite kind.

Question 13. What is meant by doubling up charge?

Answer. Suppose one (A) of two insulated conductors (A and B) is charged ever so little with say + electricity. Let a third insulated conductor, which we will call a *carrier* be arranged so as to move back and forth between A and B.

Let C be touched with finger while near A.

It will acquire a small — charge. Move it over and make contact with B which will receive some — electricity. Move C a short distance from B and touch it. C will acquire a + charge by influence.

Move C over to A and let them make contact which will give some more + electricity to A. Move C away a short distance and touch it. This charges C with — electricity. Move C over to B and make contact which increases the — charge on B.

Keep this up and the charges on A and B keep increasing and by acting more strongly on C they make the increase a rapid one.

Question 14. What machines work on these principles?

Answer. The Toepler machine which has been perfected by Holtz and Voss, and the Wimshurst machine.

Question 15. Describe the Toepler machine.

Answer. The principle of the machine is described by Silvanus Thompson.

Before describing some special forms we will deal with a generalized type of machine having two fixed field-plates, A and B, which are to become respectively + and —, and a set of carriers, attached to a rotating disk or armature. Figure 21 gives in a diagrammatic way a view of the essential parts. For convenience of drawing it is shown as if the metal field-plates A and B were affixed to the outside of an outer stationary cylinder of glass;

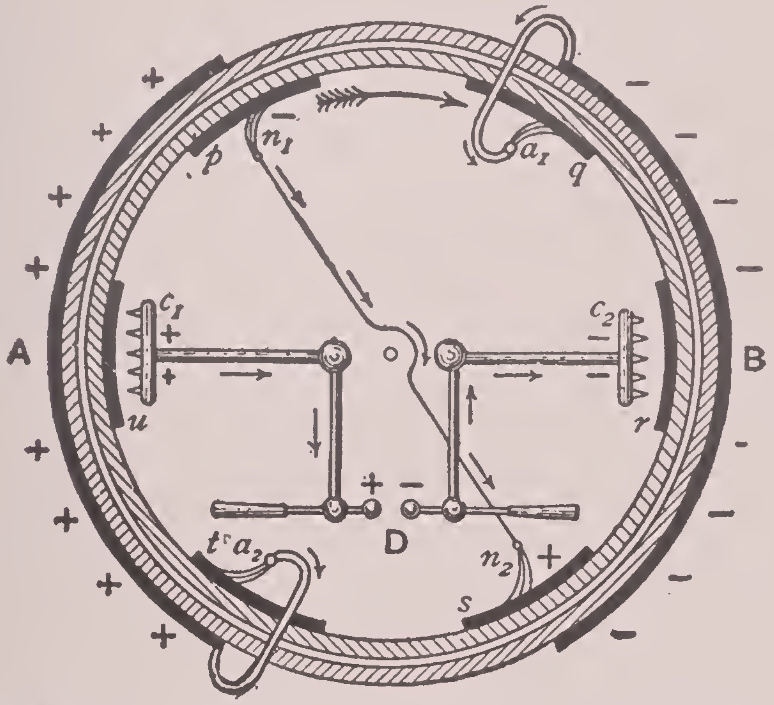


Fig. 21. Diagram to show the principles upon which the Toepler Machine operates.

the six carriers p, q, r, s, t, and u being attached to the inside of an inner rotating cylinder. The essential parts then are as follows:

(I) A pair of field-plates A and B.

(II) A set of rotating carriers p, q, r, s, t, and u.

(III) A pair of neutralizing brushes n_1, n_2 made of flexible metal wires, the function of which is to touch the carriers while they are under the influence of the field-plates. They are connected together by a diagonal conductor, which need not be insulated.

(IV) A pair of appropriating brushes a_1, a_2, which reach over from the field-plates to appropriate the charges that are conveyed around by the carriers, and impart them to the field-plates.

(V) In addition to the above, which are sufficient to constitute a complete self-exciting machine, it is usual to add a discharging apparatus, consisting of two combs c_1, c_2, to collect any unappropriated charges from the carriers after they have passed the appropriating brushes; these combs being connected to the adjustable discharging balls at D.

The operation of the machine is as follows. The neutralizing brushes are set so as to touch the moving carriers just before they pass out of the influence of the field-plates. Suppose the field-plate A to be charged ever so little positively, then the carrier p, touched by n, just as it passes, will acquire a slight negative charge, which it will convey forward to the appropriating brush a_1, and will thus make B slightly negative. Each of the carriers as it passes to the right over the top will do the same thing. Similarly each of the carriers as it passes from right to left at the lower side will be touched by n_2 while under the influence of the — charge on B, and will convey a small + charge to A through the appropriating brush a_2. In this way A will rapidly become more and more +, and B more and more —; and the more highly charged they become, the more do the collecting combs c_1 and c_2 receive of unappropriated charges. Sparks will snap across between the discharging knobs at D.

The machine will not be self-exciting unless there is a good metallic contact made by the neutralizing brushes and by the appropriating brushes. If the discharging apparatus were fitted at c_1, c_2 with contact brushes instead of spiked combs, the machine would be liable to lose the charge of the field-plates, or even to have their charges reversed in sign whenever a large spark was taken from the knobs.

It will be noticed that there are two thicknesses of glass between the fixed field-plates and the rotating carriers. The glass serves not only to hold the metal parts, but prevents the possibility of back-discharges (by sparks or winds) from the carriers to the field-plates as they pass.

Toepler's Influence Machine.—In this machine, as constructed by Voss, are embodied various points due to Holtz and others. Its construction follows almost literally the diagram already explained, but instead of having two cylinders, one inside the other, it has two flat disks of varnished glass, one fixed, the other slightly smaller rotating in front of it (Fig. 22). The field-plates A and B consist of pieces of tinfoil, cemented on the back of the back disk, each protected by a coating of varnished paper. The carriers are small disks or sectors of tinfoil, to the number of six or eight, cemented to the front of the front disk. To prevent them from being worn away by rubbing against the brushes a small metallic button is attached to the middle of each. The neutralizing brushes n_1, n_2 are small whisps of fine springy brass wire, and are mounted on the ends of a diagonal conductor Z. The appropriating brushes a_1, a_2 are also of thin brass wire, and are fastened to clamps projecting from the edge of the fixed disk, so that they communicate metallically with the two field-plates. The collecting combs, which have brass spikes so short as not to touch the carriers, are mounted on insulating pillars and are connected to the adjustable discharging knobs D_1, D_2. These also communicate with

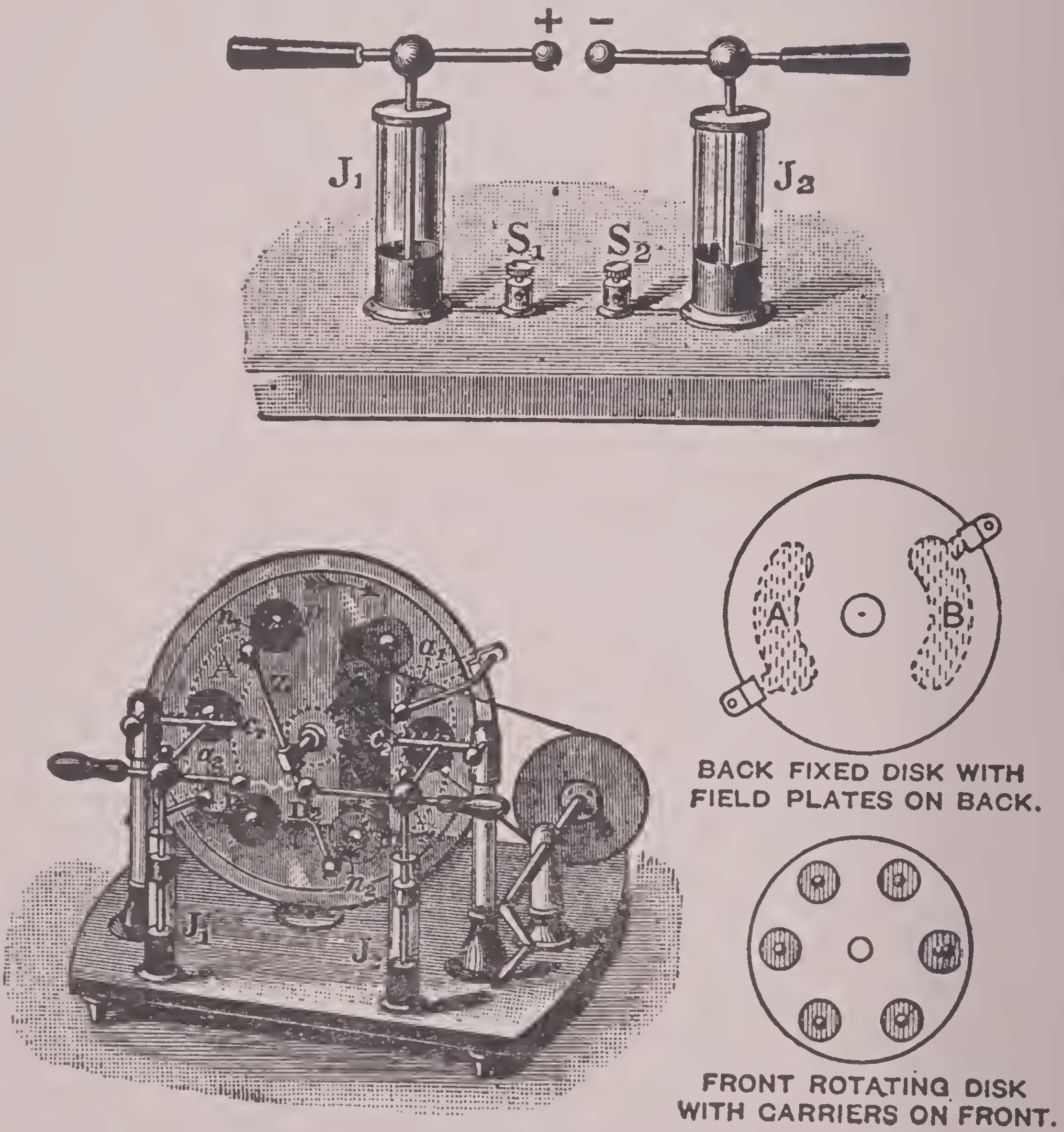


Fig. 22. A Toepler Electrical Machine.

the two small Leyden jars J_1, J_2, the function of which is to accumulate the charges before any discharge takes place. These jars are separately depicted in Fig. 22. Without them, the discharges between the knobs take place in frequent thin blue sparks. With them the sparks are less numerous, but more brilliant and noisy.

To use the Toepler (Voss) machine first see that all the four brushes are so set as to make good metallic contact with the carriers as they move past, and that the neutralizing brushes are set so as to touch the carriers while under influence. Then see that the discharging knobs are drawn widely apart. If it is clean it should excite itself after a couple of turns, and will emit a gentle hissing sound, due to internal discharges (visible as blue glimmers in the dark), and will offer more resistance to turning. If then the knobs are pushed nearer together sparks will pass across between them. The jars (the addition of which we owe to Holtz) should be kept free from dust. Sometimes a pair of terminal screws are added at S_1, S_2 (Fig. 22) connected respectively with the outer coatings of the jars. These are convenient for attaching wires to lead away discharges for experiments at a distance. If not so used they should be joined together by a short wire, as the two jars will not work properly unless their outer coatings are connected.

Question 16. Describe the Wimshurst machine.

Answer. Silvanus Thompson describes it as follows:

In this, the most widely used of influence machines, there are no fixed field-plates. In its simplest form it consists of (Fig. 23) two circular plates of varnished glass, which are geared to rotate in opposite directions. A number of sectors of metal foil are cemented to the front of the front plate and to the back of the back plate; these sectors serve both as carriers and as inductors. Across the front is fixed an uninsulated diagonal conductor, carrying at its ends neutralizing brushes, which touch the front sectors as they pass. Across the back, but sloping the other way, is a second diagonal conductor, with brushes that touch the sectors on the hinder plate. Nothing more than this is needed for the machine to excite itself when set in rotation; but for convenience there is added a collecting and discharging apparatus. This consists of two pairs of insulated combs, each pair having its spikes turned inwards

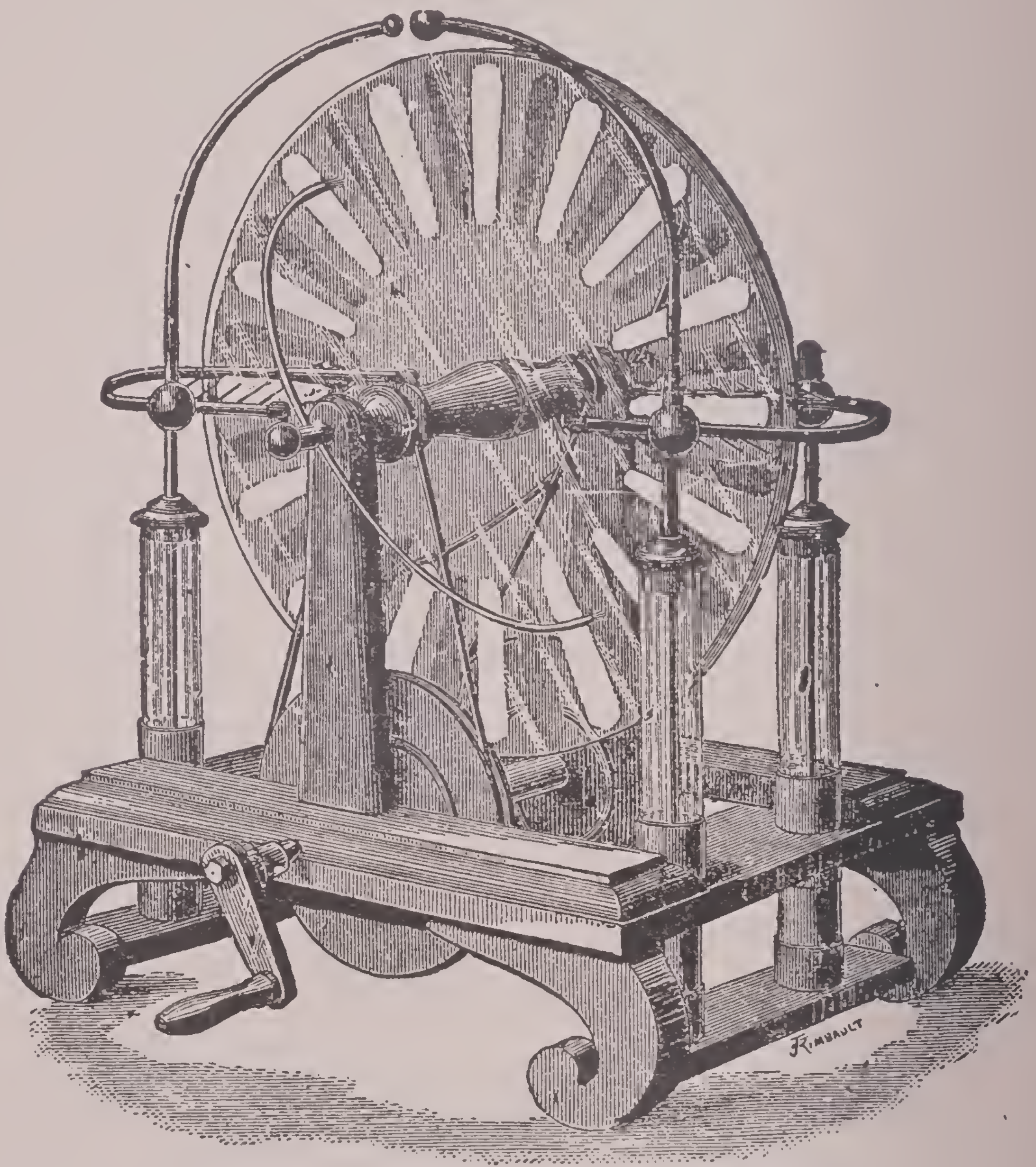


Fig. 23. A Wimshurst Electrical Machine.

toward the revolving disks, but not touching them; one pair being on the right, the other on the left, mounted each on an insulating pillar of ebonite. These collectors are furnished with a pair of adjustable discharging knobs overhead; and sometimes a pair of Leyden jars is added, to prevent the sparks from passing until considerable quantities of charge have been collected.

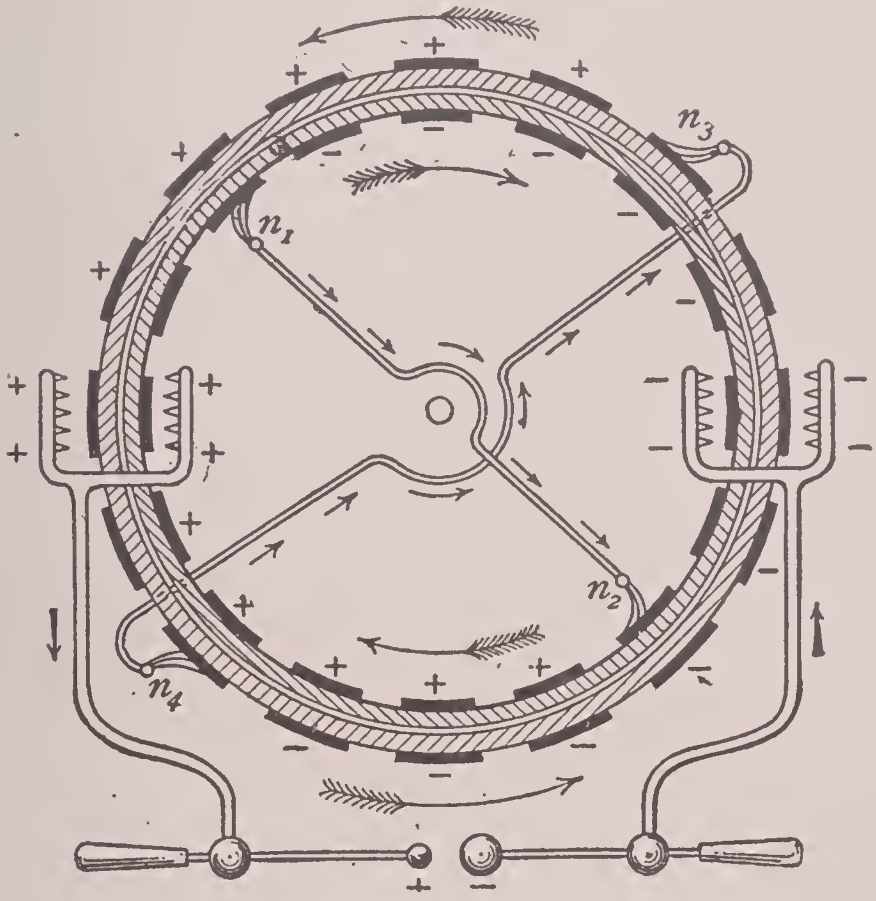


Fig. 24. The Wimshurst Machine laid out in diagrammatic way, to show principle of its operation.

The processes that occur in this machine are best explained by aid of a diagram (Fig. 24), in which, for greater clearness, the two rotating plates are represented as though they were two cylinders of glass, rotating opposite ways, one inside the other. The inner cylinder will represent the front plate, the outer the back plate. In Figs. 23 and 24 the front plate rotates right-handedly, the back plate left-handedly. The neutralizing brushes n_1, n_2 touch the front sectors, while n_3, n_4, touch against the back sectors.

Now suppose any one of the back sectors represented near the top of the diagram to receive a slight positive charge. As it is moved onward toward the left it will come opposite the place where one of the front sectors is moving past the brush n_1. The result will be that the sector so touched while under influence by n_1 will acquire a slight negative charge, which it will carry onward toward the right. When this negatively-charged front sector arrives at a point opposite n_3 it acts inductively on the back sector which is being touched by n_3; hence this back sector will in turn acquire a positive charge, which it will carry over to the left. In this way all the sectors will become more and more highly charged, the front sectors carrying over negative charges from left to right, and the back sectors carrying over positive charges from right to left. At the lower half of the diagram a similar but inverse set of operations will be taking place. For when n_1 touches a front sector under the influence of a positive back sector, a repelled charge will travel along the diagonal conductor to n_2, helping to charge positively the sector which it touches. The front sectors, as they pass from right to left (in the lower half), will carry positive charges, while the back sectors, after touching n_4, will carry negative charges from left to right. The metal sectors then act both as carriers and as inductors. It is clear that there will be a continual carrying of positive charges toward the right, and of negative charges to the left. At these points, toward which the opposite kind of charges travel, are placed the collecting combs communicating with the discharging knobs. The latter ought to be opened wide apart when starting the machine, and moved together after it has excited itself.

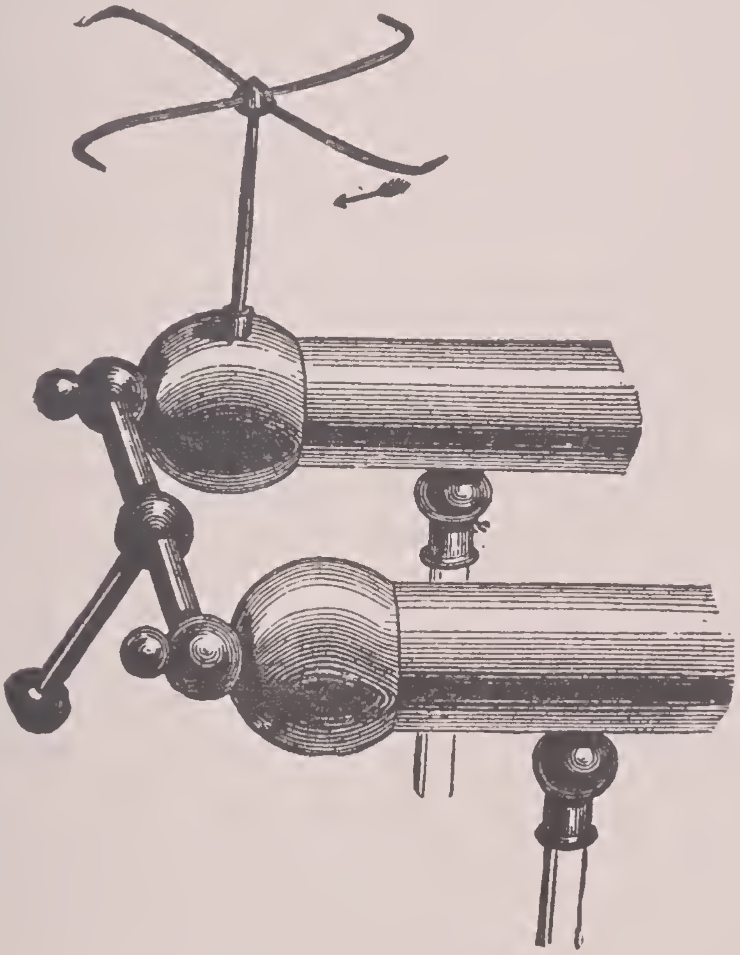


Fig. 25. Electrical Wheel.

In larger Wimshurst influence machines two, three, or more pairs of oppositely-rotating plates are mounted within a glass case to keep off the dust. If the neutralizing brushes make good metallic contact these machines are all self-exciting in all weathers. Machines with only six or eight sectors on each plate give longer sparks, but less frequently than those that have a greater number. Mr. Wimshurst has designed many influence machines, from small ones with disks 2 inches across up to that at South Kensington which has plates 7 feet in diameter.

Prior to Wimshurst's machine Holtz had constructed one with two oppositely-rotating glass disks; but they had no metal carriers upon them. It was not self-exciting.

Question 17. Give some experiments showing the action of electricity.

Answer. Example 1. If a pivot be erected on the knob of an electric machine and a small wheel with wire spokes bent as shown in Fig. 25 is balanced on the pivot, the electrical winds coming from the pointed ends will drive the wheel around.

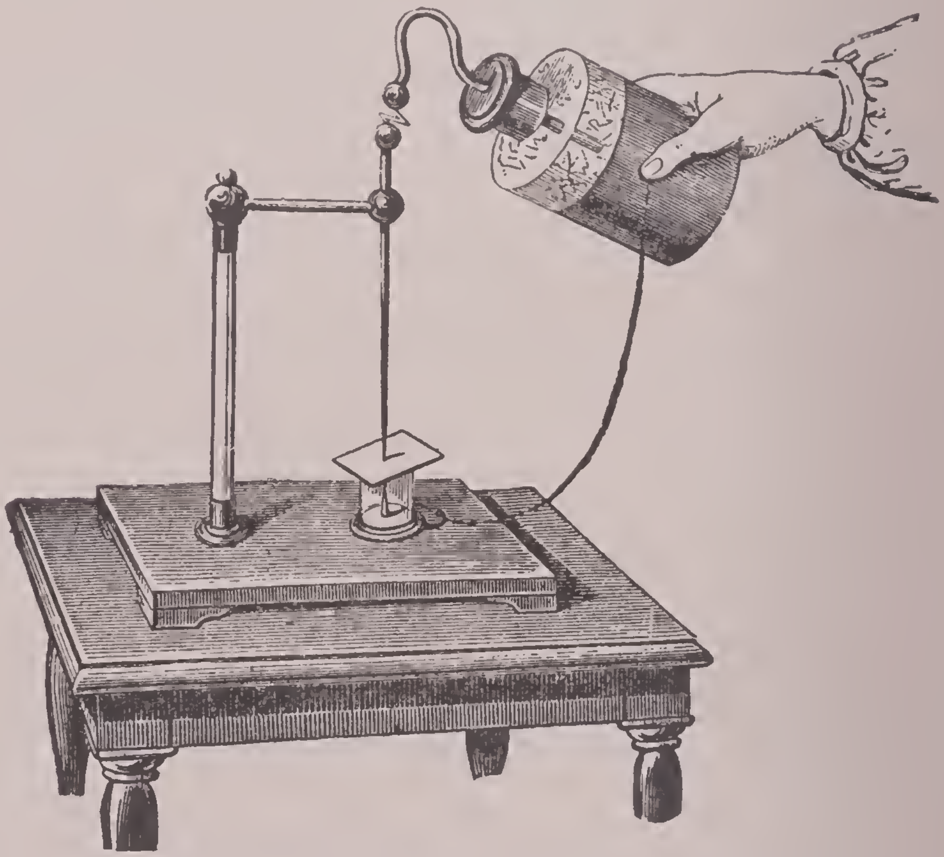


Fig. 26. Puncturing a Card with Spark from a Leyden Jar.

Example 2. A card may be punctured as shown in Fig. 26. There will be a burr on both sides of the hole in the card as if the material were pulled out from the card on both sides at the same time.

Example 3. A fine wire melted as shown in Fig. 27.

Example 4. When an electrical machine is actuated in the dark, accompanying the slight crackling which indicates leaking, at several points on the frame may be seen luminous appearances, called brushes; and if a conductor, a wire, or the hand, be presented toward the terminal of the machine, just beyond the striking distance of a spark, one of these brushes will reach for the object so presented. The brush discharge consists of a short stalk, from which spreads a shape not unlike a palm leaf fan, consisting of rays which become thinner and lighter towards their outer extremity.

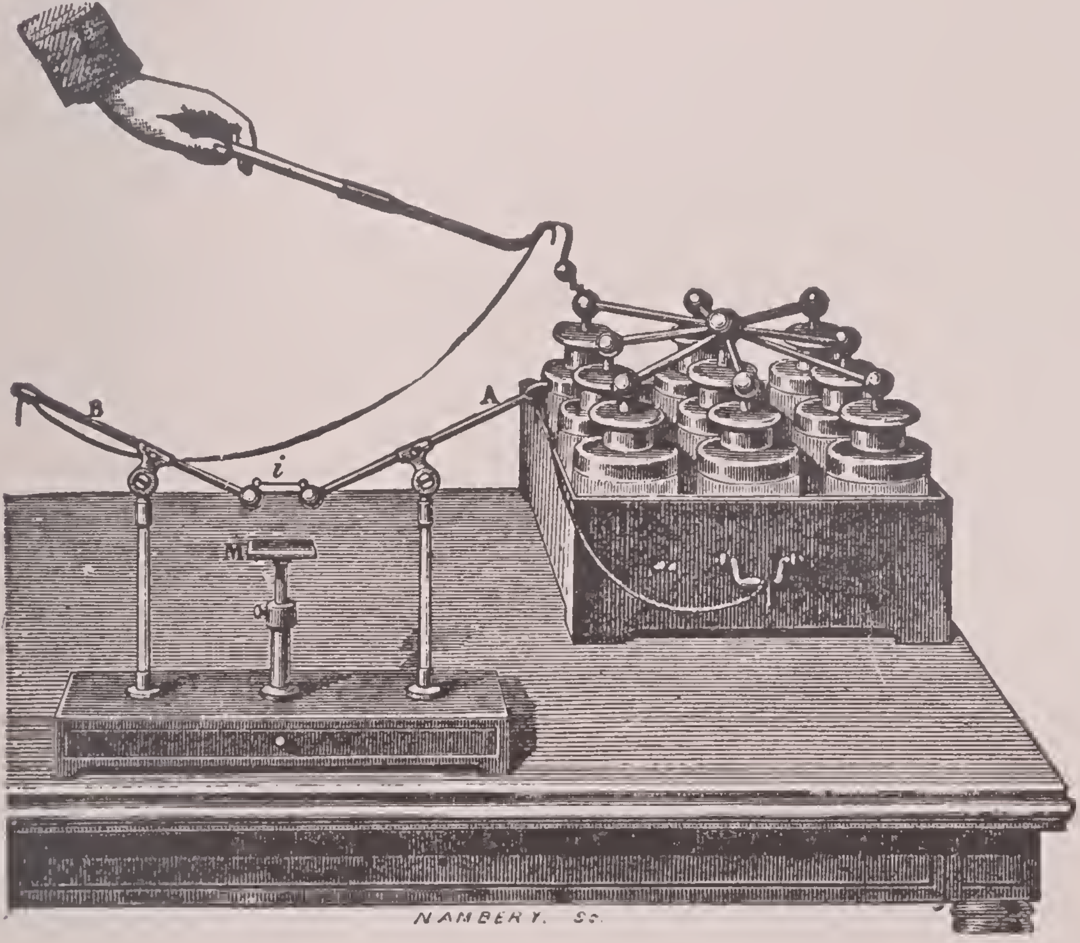


Fig. 27. Melting a Wire with a Battery of Leyden Jars.

Example 5. If a doll's head having hair, be placed on the terminal of the machine, and the machine actuated, the hair will tend to straighten out in all directions, and will reach for the hand or other conductor presented. Discharging the machine by placing its terminals in contact, will restore the hair to its normal condition.

Example 6. A human leyden jar may be made by a person occupying a stool or chair, the legs of which are standing in dry India rubber overshoes, in tumblers, or in telegraph insulators. In this position the human leyden jar is capable of being charged, and of giving shocks to parties standing on the floor or ground. The hair of the human jar will stand on end if the charge is considerable, and be attracted by the approach of any conductor. The charge may be silently discharged through a fork or needle held in the hand.

Example 7. Attach a rod or heavy wire to the terminal of the machine, having the curved shape of a shower bath standard, and terminating in a metal band, the lower edge of which is fitted with points like an inverted crown. One sitting or standing beneath such an attachment will feel a very perceptible breeze.

Example 8. Approach the knob of a machine with a sharp needle held in the hand, and the discharge will be noiseless and not unpleasant. If in a darkened room, the discharge will be seen to resemble a blue flame.

Question 18. It is said that static electricity is only on the surface of charged bodies. Is this true?

Answer. Yes, as is shown by this experiment.

On the top of a rod of glass which is fastened to a sufficiently heavy base, a brass ring is fixed in a vertical position. To this ring, much like a minnow or landing or butterfly net frame, is attached a fine linen bag, which runs down to a point—like an elongated cone. A silk thread extends from the apex or point of the cone, in each direction, so that the bag may be reversed at will by pulling on the one thread and loosing the other. Now, when this bag is charged a test shows electricity on the outside, and none on the inside of the net, in all cases. Reversing the bag reverses the surface electrified, no matter how often or how suddenly the change is made. See Fig. 28.

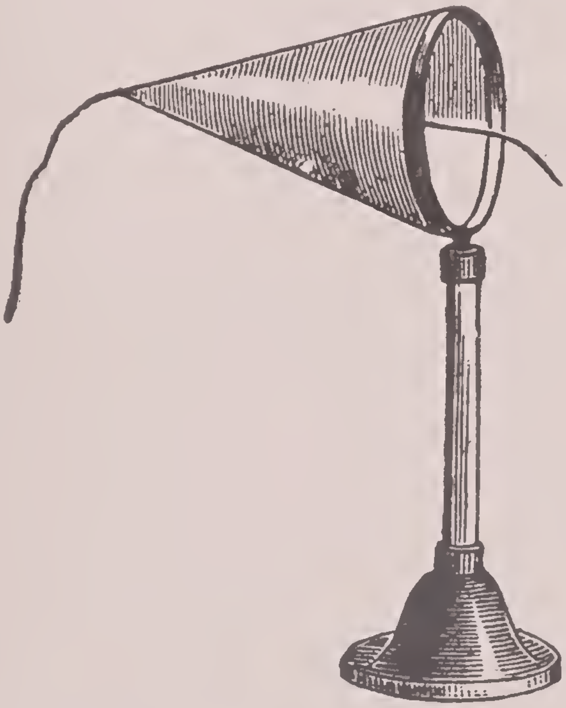


Fig. 28. Static Electricity always stays on Outside of Body.

Question 19. Is the charge spread evenly over the whole surface?

Answer. No. The density of electricity residing on the surface of a conductor sufficiently removed from bodies affecting it as to be uninfluenced by them, is materially dependent as to distribution, on the shape of the charged body. For instance, a perfect metallic sphere shows the same electrical density over all portions of its surface, and while the charge of a metallic disc is hardly appreciable on the two surfaces, yet close to the edges it increases rapidly to the outer limit of the body. See Fig. 29.

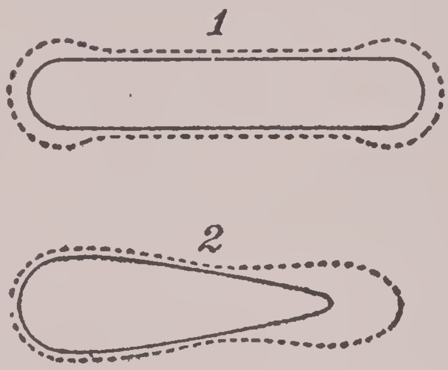


Fig. 29. Distribution of Electrical Charge over the surface of a body, showing influence of edges and points.

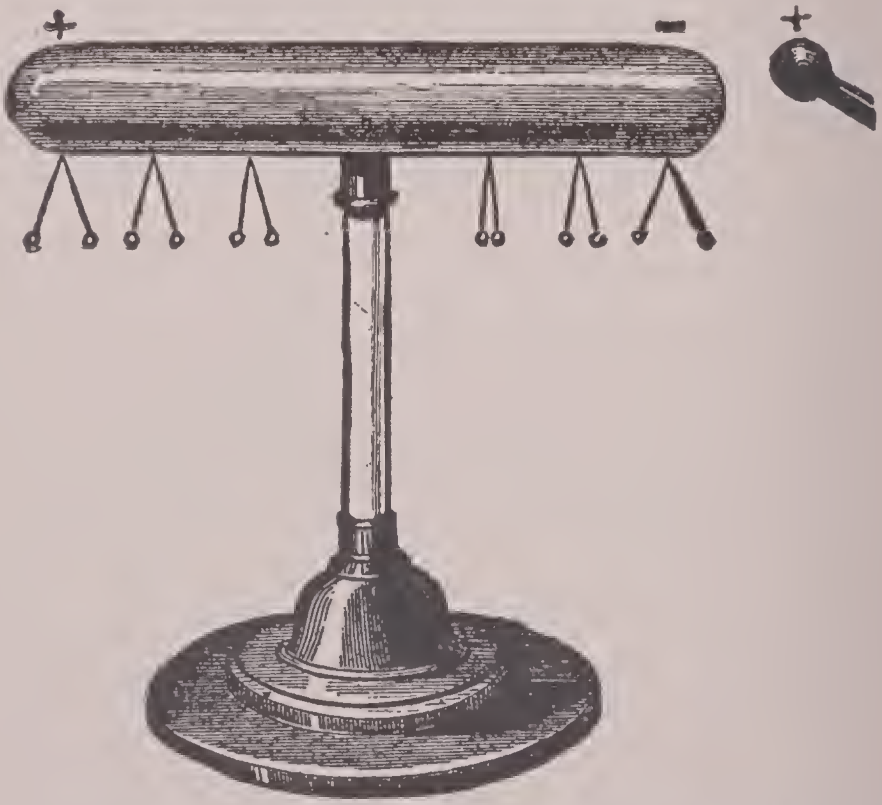


Fig. 30. Charge on a Conductor. Shows Density at Different Points.

This density increases at all pointed as well as rounded extremities. The density is greatest on the most projecting parts of the surface, or those which have the sharpest convexity, while hollows and indentations show little or no charge. In consequence of this strain, at a sharp projection on a charged conductor, or still more markedly, at a point, as in a sharpened wire, the condensation of such an amount of force within such small space produces a very rapid escape of electricity from such points. For this reason conductors which it is desired should retain their charge should have no edges or points, and must be very smooth. This is why the terminals of leyden jars and other similar apparatus are in the form of knobs and the combs of electrical machines are, like lightning rods, pointed, to facilitate silent, rapid leaking.

The density of the charge is also shown by the relative repulsion of the pith balls at different points on the surface, as in Fig. 30.

LESSON 6.

LIGHTNING.

ATMOSPHERIC ELECTRICITY.

The similarity in the effects of lightning and those of the electric spark enlisted the minds of the earliest physical investigators. Lightning ruptures and disintegrates substances opposing its passage, and where these are combustible, often ignites them. It is capable of producing all the effects of heat in melting metals, and volatilizing them, and leaves behind it, in many instances, the odor which we recognize as that pertaining to ozone. This odor is the same that is observed when an electrical machine has been working a few minutes. To Franklin is given the credit of thoroughly identifying the phenomena of proving experimentally with his historic kite, and the aid of leyden jars, that, excepting the factors of quantity and intensity, the two were one.

Franklin enumerated the following specific characteristics pertaining to, and tending to show that lightning and the spark were but different manifestations of static electricity: "Giving light; color of the light; crooked direction; swift motion; being conducted by metals; noise in exploding; conductivity in water and ice; rending imperfect conductors; destroying animals; melting metals; firing inflammable substances; sulphureous smell (ozone); and similarity of appearance between the brush discharge from the tips of masts and spars sometimes seen at sea, called St. Elmo's fire by the sailors, and the slow escape from points on an electrical machine or a leyden jar."

The cause of electrical charges in the atmosphere is unknown, there are half a dozen explanations any one of which or all may be correct.

A Brush Discharge of Lightning.

It is generally agreed, however, that the cause of lightning is the condensation of water vapor in clouds.

Thunder Storms.—One of the most interesting manifestations of statical electricity is the thunder shower which is brought about in this way. Although bodies cannot be charged throughout their substance, the electricity being always on the surface of the body; yet clouds seem to be electrified all the way through. This is because a collection of little particles of water, like a rain cloud, can have a charge on the surface of each particle.

As the particles of water fall by gravitation many touch and unite, so that the charges of say eight small drops are now in a drop weighing eight times as much, but which has only half the surface of the eight, hence the pressure is four times as large. This occurs in the following manner:

Since the surface of a sphere is equal to the product of the square of its diameter and the fraction twenty-two sevenths and the volume of a sphere is equal to one-sixth of the product of twenty-two sevenths and the cube of the diameter, we can calculate as follows:

Eight spherical rain drops each 1 mil* in diameter have a total surface of 25 sq. mils. They have a total volume of 4.2 cu. mils. Now the sphere composed of the eight drops has the same volume i. e. 4.2 cu. mils and we can find its diameter from the rule: The diameter of a sphere is the cube root of the continued product of its volume, six, and seven twenty-seconds. Applying this we find the diameter to be 2 mils, hence its surface is 12.5 sq. mils. That is exactly one-half the surface of the eight separate drops.

---

* Note.—A mil is the name given in machine shops and in all electrical work to one-thousandth of an inch.

The mathematical work of the above is here given in full.

Twenty-two sevenths is a convenient and quite accurate way of expressing the number 3.1416.

Total surface of eight spheres
$8 \times 3.1416 \times 1 \times 1 = 25$ sq. mils.

Total volume of eight spheres
$8 \times 0.166 \times 3.1416 \times 1 \times 1 \times 1 = 4.2$ cu. mils.

Volume of the large sphere $= 4.2$ cu. mils.

Diameter of large sphere is the cube root of
$4.2 \times 6 \div 3.1416 = 8$ mils.

Cube root of $8 = 2$ mils.

Surface of large sphere
$3.1416 \times 2 \times 2 = 12.5$ sq. mils.

$25 \div 12.5 = 2$. So large sphere has only half surface of eight small ones.

Therefore the eight charges having been squeezed into the surface where only two were before, the pressure must be four times as great.

By the repeated union of these larger drops, the pressure becomes very high, and meanwhile the influence of the charged cloud is to accumulate a charge of the opposite name in the earth under the cloud. This in turn increases the pressure. When finally the pressure gets high enough the air is punctured, and the spark jumps between earth and cloud. It literally punches a hole in the atmosphere and the inrush of air to fill the hole causes the loud sounding thunder.

There are two kinds of atmospheric electricity different enough to need different devices to guard against their effects. Some forms of lightning arresters combine both devices in the one piece of apparatus.

Lines are sometimes struck by lightning. This means that an accumulation of electricity suddenly makes connection with the line, discharging through it, its machinery and instruments.

A stroke discharges violently and cannot be discharged by degrees, for the line is not strained until the lightning strikes.

Lines are often affected by "static," which means that electricity has accumulated on the line until its pressure is high enough to do damage when discharging along the line through machinery, etc.

Static changes can accumulate on long open air lines as well as on lead sheathed cables.

The cable insulator makes a dielectric and the lead cover and copper conductor the two plates of a condenser.

In the open air line the two wires of the circuit form the plates and the air between the dielectric. Also the two wires together and the earth form two plates with air as the dielectirc.

A transmission line 150 miles long may have a capacity of 3 mf, i. e. 1 mf per 50 miles.

Both these effects, static and strokes are summed up in the one word "lightning."

Static charges may be discharged little by little as they accumulate, so that when properly protected a line never has a static charge on it great enough to do any damage.

STATIC EFFECTS ON CIRCUITS.

On high voltage alternating current lines not only lightning makes trouble but accidental grounds, and switching operations some times cause "static effects."

This use of the word static is hardly a good one as these effects are all due to a wave of electricity flowing over the circuit. This wave is the flow of an electrostatic charge from one point of the circuit to another.

When a disturbance is created at any point of an electric circuit as the sudden opening of a field circuit, an arc jumping across the lines, the release of a large "bound" static charge, or the striking of lightning, etc., a set of waves of electricity are started just as when a stone is thrown into a narrow stream of smooth water.

Our troubles are caused by "static" electricity, but are actually produced by the wave or surge following the disturbance.

The damage done by a surge depends on the condition of the circuit, whether dead,* live or loaded, the excellence of its arresters in design and state of repair.

We will make this distinction between lightning and other static troubles.

When we say *lightning* we mean an actual stroke and its effects at the point of striking.

When we say *surge* we mean any or all static electrical troubles on the lines at points where the lightning did not strike.

Lightning can do damage by striking and producing a surge at the same time.

A surge is electricity at very high pressure and very great frequency; the normal current on a line is of moderate pressure and low frequency.

The normal current is produced by the generators.

Surges may be produced by

1. Switching off live lines from a station.
2. Switching on dead transmission lines, branch lines, transformers, or underground cables to a station or to a live line.
3. Short circuits which are sudden.

---

*A dead line is one not connected to any source of electricity. A live line is one connected to a generator in operation or another circuit and has pressure on it ready to deliver power. When lamps, motors, etc., are connected to a live line it carries the current to operate them and is called a loaded line.

4. Grounds or partial short circuits which occur suddenly.

5. Lightning stroke.

By high pressure we mean any pressure over 50% greater than the line voltage.

Frequency is best explained as follows:

If the feed wire of a city trolley line be cut and a pressure indicator inserted the pointer will stand rather steady at about 500 volts. This shows a steady current.

If, however a feed cable from one of the main power stations to a sub-station be cut and a pressure indicator inserted (called an oscilligraph), the instrument will show that the pressure is constantly and very rapidly changing from a high value to a low one, then reversing and going down to a high negative value and coming back to zero.

The pressure keeps rising and falling and alternating positive and negative.

It will make from 15 to 33 of these complete changes, called cycles, every second. The frequency with which these changes occur is called the frequency.

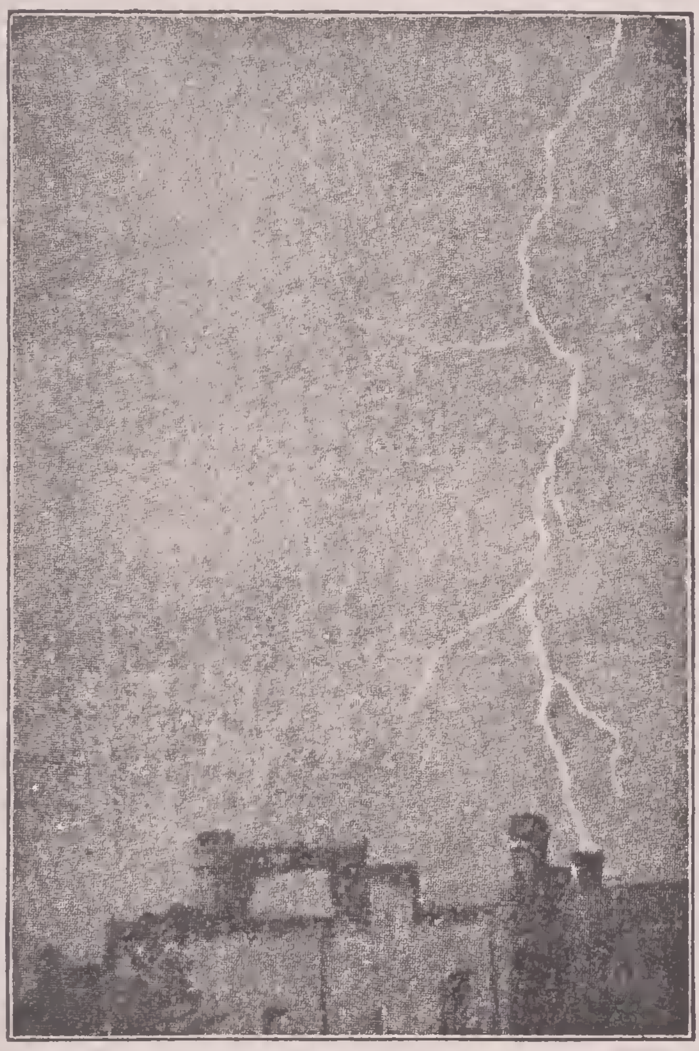
Frequency is then the number of cycles per second.

Take a transmission line delivering power at the distant end where the capacity is about 3 mf.

While this line is in operation supplying power, the current varies, according to the load. When all the motors it supplies are stopped and all the transformers at the other end are cut off there is no load but still about 50 amperes flow into the line.

This current is charging the line, that is, keeping up the voltage of the line; for the line is a condenser and takes current to charge it.

If a switch is opened when the line is loaded there would be an arc formed at the switch blades on account of the large current broken and the discharge of the line itself.



A Lightning Stroke.

If a switch is opened when the line is simply alive, that is, charged but not loaded, there is a slight arc at the switch due to the discharge of the line.

If the generators are stopped and the line is "dead" of course there is then no arc at the switch opening.

The arc formed by the opening of a loaded line allows the line to discharge itself across the arc, but when the switch to a live line is opened quickly the small arc dies out, leaving the line lightly charged. The line will now discharge itself at the weakest point along its insulation unless provided with arresters to discharge it in a harmless manner.

The surge of the charge may raise the pressure on this cut out* line to double the pressure of the generators. A 22000 volt line may rise to 44000 volts when suddenly cut out.

When a single phase generator (See Lesson 28) is grounded at one terminal and a "live" branch line connected to its other terminal is cut at the switch-board the pressure caused by the surge may rise to four times the original pressure. So a 40000 volt line might have one of its branch lines rise to 120000 volts.

The two cables from a single phase generator to the switch board are called its terminals.

When a dead line is "cut in"* its capacity must be filled up and there is a sudden rush of current into it. This produces a surge along the line and when the line is short the pressure may rise to double the normal pressure. When the line is long it hardly ever rises to quite double pressure.

It is interesting to know that the first dead line switched on to the generators has the least rise in pressure, and the last switched on the greatest. So the line with the weakest insulation or poorest arresters may be switched on first.

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*To cut in a line is to connect it to the generator or to the main transmission line; to cut out is to disconnect it. A cut out line is one which has been disconnected.

When a "dead" transformer is connected to a live line there is a surge, and due to the choking effect of the coils in the transformer, this surge only penetrates a short distance. The turns of wire near the end of a transformer are insulated with extra thickness of material to protect them, and arresters should be placed near each transformer to rid the line of the surge.

PROTECTION FROM LIGHTNING.

Persons.

Question 1. What precautions should people take during lightning discharges?

Answer. Do not stand in the open doorway of a building or under a single tree in a field. Standing under a group of trees is not so bad. Do not stand near a wire fence.

Question 2. Won't steel articles attract lightning?

Answer. No, nothing attracts lightning, it merely goes by the shortest path whose resistance is fairly low.

Question 3. Is not staying in a locomotive dangerous, especially electric ones?

Answer. No, it is the safest place you can be, as the metal is all around and acts as a shield, carrying the discharge safely past the person.

Question 4. What is to be done to a person struck by lightning?

Answer. Treated like a person who has been suffocated, and artificial breathing begun at once, as follows.

Howard's method of producing artificial respiration has this advantage over other methods in that it can be successfully practiced by a single person, instead of two, and at the same time is equally efficacious.

"Place the subject on his back, head down and bent backward, arms folded under the head (under no conditions raise the head from the ground or floor). Place a hard roll of clothing beneath the body, with the shoulders declining slightly over it. Open the mouth, pull the tongue forward, and with a cloth wipe out saliva or mucus. Thoroughly loosen the clothing from the neck to the waist, but do not leave the subject's body exposed, for it is essential to keep the body warm; kneel astride the subject's hips, with your hands well opened upon his chest, thumbs pointing toward each other and resting on the lower end of the breastbone; little fingers upon the margin of the ribs and the other fingers dipping into the spaces between the ribs. Place your elbows firmly against your hips, and using your knees as a pivot press upward and inward toward the heart and lungs, throwing your weight slowly forward for two or three seconds, until your face almost touches that of your patient, ending with a sharp push which helps to jerk back to your first position. At the same time relax the pressure of your hands so that the ribs, springing back to their original position, will cause the air to rush into the subject's lungs. Pause for two or three seconds, and then repeat these motions at the rate of about ten a minute, until your patient breathes naturally, or until satisfied that life is extinct. If there is no response to your efforts persistently and tirelessly maintained for a full hour, you may assume that life is gone.

"Hot flannels, water bottles, bricks, and warm clothing will aid in recovery. Warmth should be maintained, but nothing must prevent persistent effort as above described. Stimulants in small quantities may be administered after swallowing is possible, and sleep must be encouraged, as one of the best recuperatives. Get a physician as early as possible.

The treatment of persons shocked by electric light or power currents is identical with that for lightning stroke.

Buildings.

Question 5. Are lightning rods of any use?

Answer. Yes, if properly installed they offer a great protection.

Question 6. What material is best for lightning rods?

Answer. Copper, as its conductivity is high, and so is much lighter, smaller and neater in appearance than an iron rod.

Question 7. What should they weigh?

Answer. A copper rod six ounces to the lineal foot and an iron rod two pounds per lineal foot.

Question 8. What kind of rod should be used?

Answer. We really do not mean a rod, the word being used in a general sense. The best form is a tape or flat thin bar.

Question 9. What kind of tips should be used?

Answer. They should be pointed.

Question 10. Why is this?

Answer. The points tend to discharge the electricity of the earth to the air and thus relieve the tension in the atmosphere.

Question 11. Where should the rods be placed?

Answer. Tips should be erected on all parts of building projecting above the roof, such as cupolas, chimneys, gables.

Question 12. What should be done to cornices, ornamental iron work, etc.?

Answer. They should all be connected by a soldered joint to a "rod."

Question 13. Should the rod be insulated from building?

Answer. No. It is certainly unnecessary from an electrical point of view and is troublesome and expensive.

Question 14. Can the "rod" be run inside the building?

Answer. Never. This would be very dangerous, as lightning if it jumped from rod would surely cause great damage.

Question 15. Must the "rods" be run straight?

Answer. It is better to run from each point on the roof as straight to the ground as possible, avoiding all sharp bends, as these give the lightning a chance to jump off.

Question 16. Does each point protect a certain area?

Answer. No. The amount of space protected by a point varies. A sudden rush or disruptive lightning discharge may strike a building very near a point. Hence the more points the greater safety.

Question 17. How are the lower ends of "rods" connected to earth?

Answer. By being well soldered to water pipes or to a plate of copper about 3x3 ft. buried in moist earth.

Question 18. If the rods pass near metal work gas pipes, etc., what should be done?

Answer. Connect them to the rod by wires whose joints are well soldered.

Question 19. Why should the joints be soldered?

Answer. Because the resistance of an old or badly made joint will sometimes cause the lightning to jump off the rod. Every joint in the rod and connections should be soldered.

Question 20. How should lightning be prevented from entering buildings by the line wires?

Answer. Use lightning arresters at the point where they enter the building.

Question 21. What is a lightning arrester?

Answer. It is a device designed to protect electrical apparatus from lightning or atmospheric electricity.

Question 22. Does it stop the lightning?

Answer. No, the name arresters is misleading. They do not stop the discharges, but turn them aside to a conductor which leads to the ground.

Question 23. What circuits need protection?

Answer. Any circuit which has a part running out doors, or any circuit connected to one running into the open air.

Question 24. What kinds of circuits need protection most?

Answer. Long lines, lines running over hills or mountains.

Question 25. Does the kind of power on the line affect the liability of lightning discharge?

Answer. No, any kind of line from telegraph to power transmission is equally liable to be struck.

Question 26. Do the station men sometimes disconnect the dynamos from the line to prevent the line being struck?

Answer. No, they do it when they mistrust the lightning arresters' ability to protect the dynamos. Cutting the dynamos off puts them in safety, but the line is not protected. A dead line is just as apt to be struck as a live one.

Question 27. Are some parts of the country troubled with lightning more than others?

Answer. Yes. In the Rocky Mountains lightning discharges are very numerous and severe.

Question 28. What trouble may result from lightning striking a line?

Answer (1) Burning of insulation on wires in instruments and machines.

(2) Puncturing insulation of machinery, like dynamos or transformers. Either of these destroys the insulating value of the material.

(3) Melting of wires or fusing together metal parts which are in contact.

(4) Dangerous injuries to persons.

(5) Fire caused by an arc jumping across inflammable material.

(6) The insulators are sometimes cracked or even splintered.

(7) Poles are splintered or sometimes shattered.

(8) A cable forming a part of the current is more likely to have its insulator punctured than any other part of the circuit. This is a very troublesome and costly thing to repair.

This applies to underground or underwater cables more than to those strung on poles.

Question 29. Does lightning follow the shortest path or the path of least resistance?

Answer. Unlike ordinary current electricity, lightning usually follows the straight, short path even if of enormous resistance.

Question 30. Does a break in the circuit stop lightning?

Answer. No, it will jump across and go on.

Question 31. Do coils have any effect on lightning?

Answer. Yes. Lightning cannot pass readily through a coil of wire. It will do so if this is the only path open to it, but if there is any other path not containing coils the lightning will usually take the path without coils. It sometimes jumps from turn to turn of a coil, thus getting past without going through.

Errata:—Illustration on page 102 should read Shunt Circuit in lower part instead of Short Circuit.

LESSON 7.

LIGHTNING ARRESTERS.

LOW VOLTAGE.

Question 1. What is the oldest form of arrester?

Answer. The saw tooth spark gap of the telegraph offices.

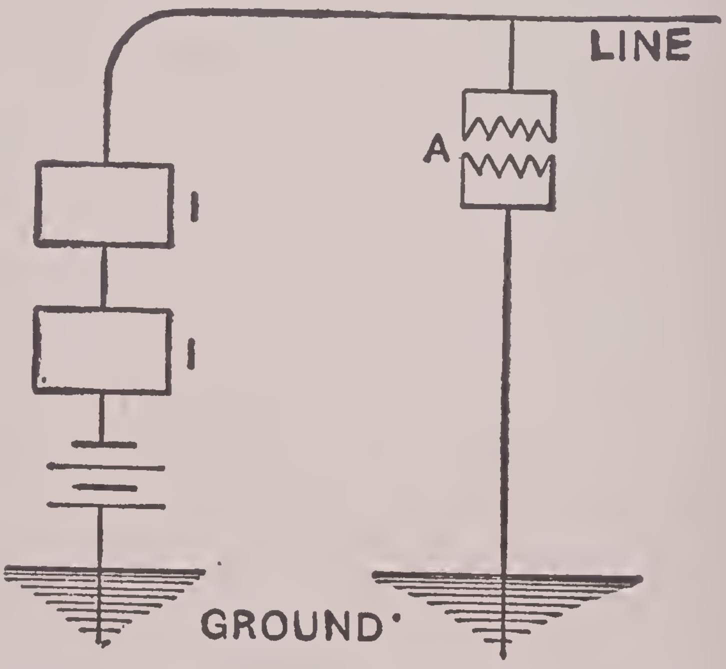

Fig. 31. The Saw-tooth Lightning Arrester as used on Telegraph Circuits. I and I are the Instruments and A the Arrester.

Question 2. Describe it.

Answer. Two brass plates with V-shaped points are set close to each other on an insulating base, one plate is connected to the line and the other to a ground plate buried in the earth. (See Fig. 31.)

Question 3. How does it operate?

Answer. The lightning being of an electrostatic nature discharges from points readily, and being of an enormous pressure is able to jump the air gap between the points. The telegraph instruments contain electro magnets whose coils act as choke coils.

The lightning has the choice of the path through the instrument coils or across the air gap. It practically always takes the air gap and runs to the earth through the ground wire.

Question 4. What objection is there to this type of arrester when power circuits are to be protected?

Answer. The spark caused by the lightning in leaping across the air gap forms a conducting path between the plates.

The pressure on the line due to the generators sends the current across this path which forms an arc melting the edges of the plates.

This arc grows larger until it conducts enough current to "blow"* the fuses in the circuit, which interrupts the service.

The arcing of an arrester is always caused by the current of the line following the sparks due to lightning discharge.

Question 5. What is the easiest way of stopping the working current from following the lightning discharge?

Answer. Place small fuses (as in Fig. 32) in the ground wires of the arresters before they join to the common† ground wire. Then any working current following the lightning discharge will blow these fuses instantly.

---

*Melt.

†A wire acting as a ground wire for several others is called a "common" ground wire.

leaving the main fuses unharmed. This will not interrupt the service.

Question 6. What is the objection to the arrangement?

Answer. Often the two fuses are blown, the arrester is useless and machinery left unprotected, there being no ground connection to conduct the discharge away.

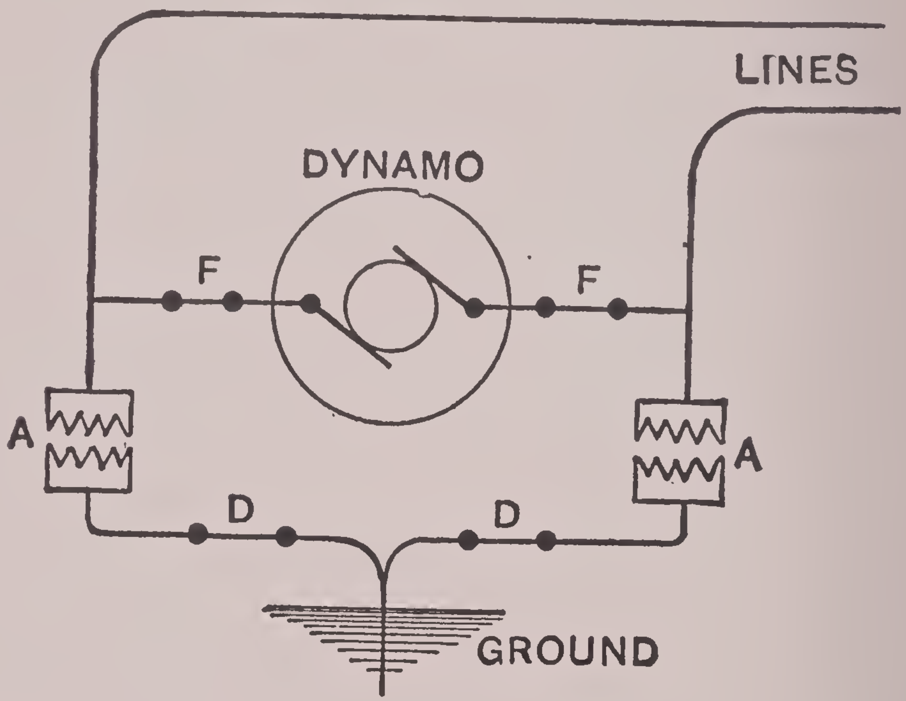

Fig. 32. The Saw-tooth arrester applied to a Dynamo. F, F are the regular fuses. D, D are the fuses for Arrester Circuit.

Question 7. But the fuses can be replaced?

Answer. Perhaps not before the next discharge has come. Moreover, a lightning arrester should allow the static charges which accumulate even in clear, dry weather to escape. These discharges sometimes snap across an arrester in the steady stream.

Question 8. What are some of the better ways of stopping the passage of the current after the discharge?

Answer. There are various ways, some methods put out the arc which is conducting the working current, and some try to prevent an arc or at least make arc very small.

Question 9. How is the arc put out?

Answer. By air blast, electromagnetic action, mechanisms for lengthening the gap momentarily as the discharge passes, also use of non-arcing metals.

Question 10. How are arcs prevented?

Answer. Smothering the arc so that it doesn't form for lack of air; insertion of resistance into the discharge circuit which weakens the current following discharge so that it cannot hold an arc.

Question 11. What should be done if an arrester in a station holds its arc?

Answer. The arc should be beaten out with a cloth or broom, or it should be smothered with sand.

Dry powder fire extinguishers are very useful for this purpose, but water or liquid extinguishers should never be used.

Question 12. Where should arresters be placed?

Answer. At the point where lines enter or leave any building, and at intervals along the line.

Question 13. Why should they be placed along the line? Will not the protectors at the buildings protect the machinery?

Answer. It seems to be generally believed now that lightning runs along the lines in waves and that at one point it may be so weak that it will not jump to ground through a certain arrester but pass on, and the same charge a few miles further on, will either be discharged through an arrester there or if there is no arrester, do considerable damage.

Hence all the most exposed places on the line should certainly have arresters and a few strung along the line will not be wasted.

Question 14. What is the best arrester?

Answer. Each kind has its good points, some will not work on low pressures, others will not stand the severe test of Rocky Mountain use, but are reasonable in price and satisfactory in action in the more open and level parts of the country.

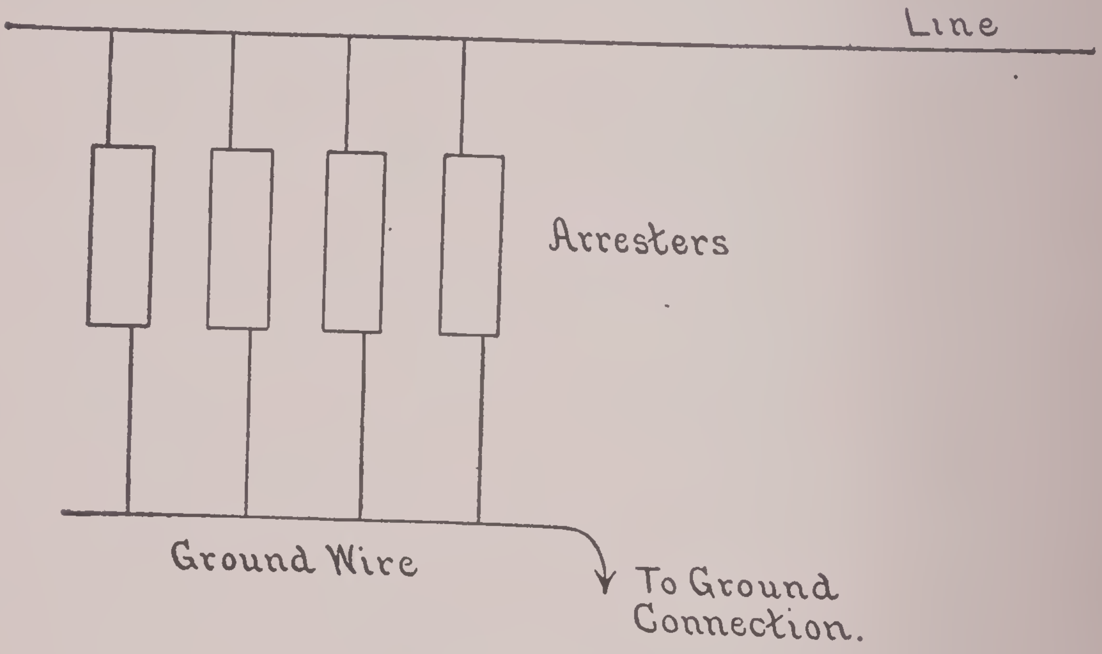

Fig. 33. Bank of Lightning Arresters.

Any arrester is hardly a complete protection unless combined with choke coils. (See Lesson 9.)

Question 15. Into what classes may arresters be divided as regards to the circuits and apparatus they protect?

Answer. (1) For use when currents are very small and voltages moderate as in telephone lines. The instruments are very delicate and need absolute protection.

(2) When currents are small and voltage moderate as in telegraph and signalling lines. Here the apparatus is heavier and less liable to damage.

(3) Power lines and lightning circuits where currents are heavy and voltage moderate, say up to 2500 volts.

(4) Power lines, transmission lines where the voltage is very high, say from 11000 up to 50000 or 60000 volts.

Question 16. Into what classes may arresters be divided as regards to the design of the arrester?

Answer. (1) Single gap arresters where one place is provided for the lightning to jump across.

Single gap arresters are often installed in banks in parallel* so that many places are provided at once.

The old saw tooth arrester is really a bank of single gaps.

(2) Multigap arresters, in which we have a number of single gaps in series.

These are sometimes simply a set of arresters in series. Each arrester being designed for say 2500 volts, using four in a series will protect a 10000 volt circuit.

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*The words series, parallel, and shunt will be more fully explained in Lesson 18, but it will be sufficient now to state that if a current goes through all of a number of instruments or resistances, they are in series. If the current splits and part goes through one set of instruments or resistances and the rest goes through another set then these two sets are in parallel.

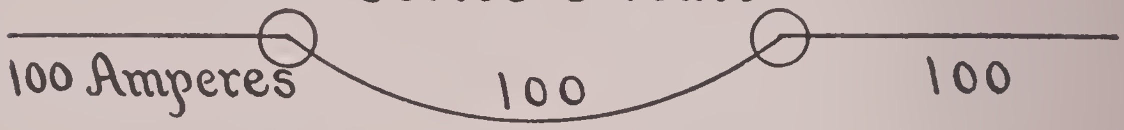
Each set while in parallel with the other set may of course consist of several pieces of apparatus in series.

When a circuit is cut and a new piece of apparatus is inserted, this piece is in series with the other.

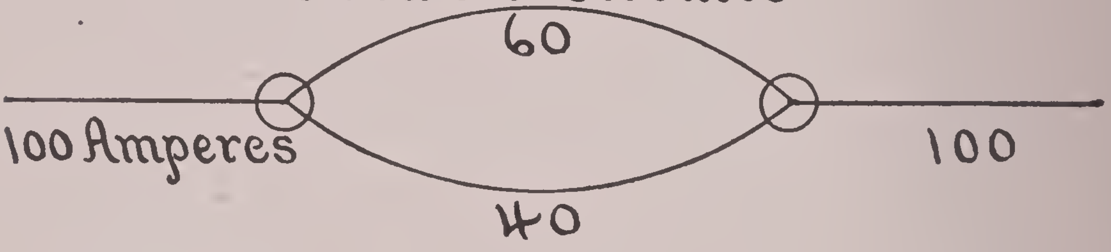
When a circuit has a new piece of apparatus attached by soldering on the wires without cutting the original circuit the new piece is a shunt circuit and the part of the old circuit is said to be shunted.

Usually they are so designed that a single arrester consists of a set of gaps in series. These arresters can be placed in series for high voltage.

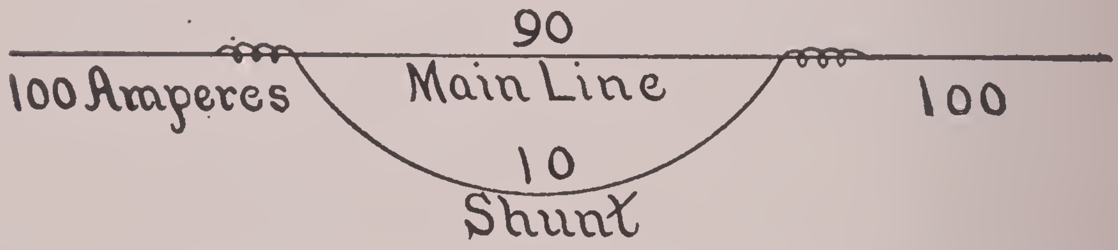
Series Circuit



Parallel Circuits



Short Circuit



The part of the main line which carries 90 amp. is shunted by the shunt which carries. 10 amperes.

(3) Arresters with series resistances. The idea being that lightning will pass through the resistance without being obstructed much while the normal line pressure cannot send enough current through the resistance to hold an arc between the discharge points.

(4) Shunted resistances. In this type a resistance is put in parallel with the spark gaps. Experiment has shown that by proper design this is very effective in preventing an arc across the discharge points.

(5) Fixed gap length. In some arresters the gap length is fixed, and resistance (series or shunt), also, and the kind of metal used for the points, is used to suppress the arc.

(6) Lengthened gaps. The gap points are shaped like horns and the heat of the arc lengthens it by the uprush of hot air or the arc is forced up by magnetism.

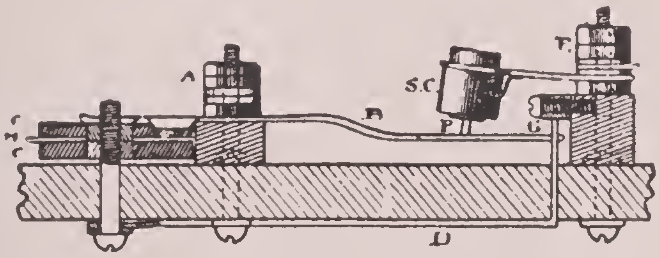


Fig. 34. Lightning Arrester and Stray Current Protector for Telephone, Bell and Signalling Circuits.

In other types the gap points are drawn apart by magnetism.

Question 17. What type of arrester is used for telephone circuits?

Answer. The protector is shown in Figs. 34 and 35. The line current enters at binding post A and passing along the spring B goes through the pin P through the wire of the coil S.C on to post E, where the instrument wire is attached.

Each side of the apparatus is just alike, there being one piece for each line wire.

On the left of post A are two carbon blocks, C and C_1, separated by a slip of mica M with a circular hole in it. The upper carbon block has a drop of fusible metal let into its lower face, but it is flush with the carbon.

The upper block is in contact with post A by a spring which holds it in position. The lower block rests on a metal plate, which is connected to the ground wire D.

When lightning or any pressure over 300 volts comes on the line it jumps across the air gap between the carbon blocks (whose length is equal to the thickness of the mica strip) and goes to ground. It at the same time melts the drop of metal, making a complete ground. The instruments are then absolutely short circuited and protected.

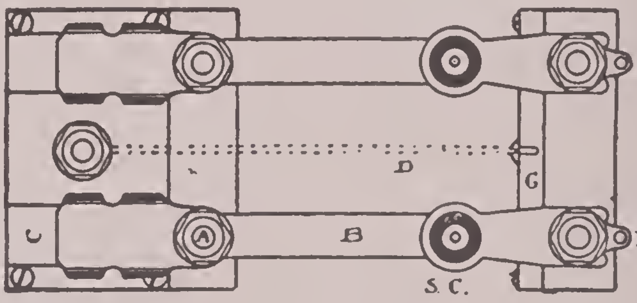


Fig. 35. Top view of Arrester shown in Fig. 34.

This means that there is a short and low resistance path for the current, which lightning will follow instead of going through the instruments.

Should there be a cross connection with other lines or a leak to the telephone line, the instruments could be damaged by the amount of current, while the pressure was far below 300 volts.

In this case the "sneak current," as it is called, goes from A along the german silver spring B, up through P and through the sneak coil SC.

The sneak coil is of very fine german silver wire, about 30 ohms resistance and in a few seconds this coil generates enough heat to melt a plug of fusible metal which holds the pin P in place.

The spring B then moves up and touches the ground strip G, thus grounding the line and protecting the instruments.

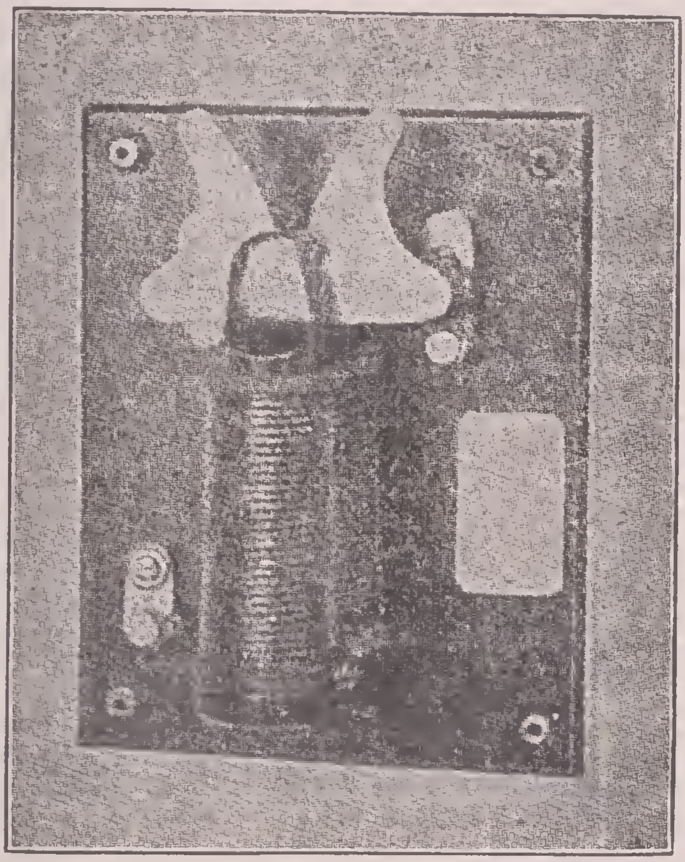


Fig. 36. Lightning Arrester with Magnetic Blow-out

Question 18. What type of arrester is used on moderate voltage lines?

Answer. One type is shown in Fig. 36. The air gap is between the curved plates. The magnet below is excited from the dynamo and the arc when formed is blown upwards until the space at the upper end of the curved plates is too long for the pressure to maintain the arc.

The instrument acts as if the arc were blown out by a puff of wind.

Another form of this arrester has two flat plates so surrounded by the magnetism that the blow out effect is stronger, and it is relied on, there being no horns to help. Both of these are used on direct current circuits.

Question 19. Describe an arrester for alternating currents at moderate voltage.

Answer. There is a non-arcing arrester for A. C.* work. It consists of seven cylinders, each one inch in diameter and three inches high. They are made of white brass with a large percentage of zinc, and very little copper, in it. They are knurled or checkered so that the surface is covered with little points.

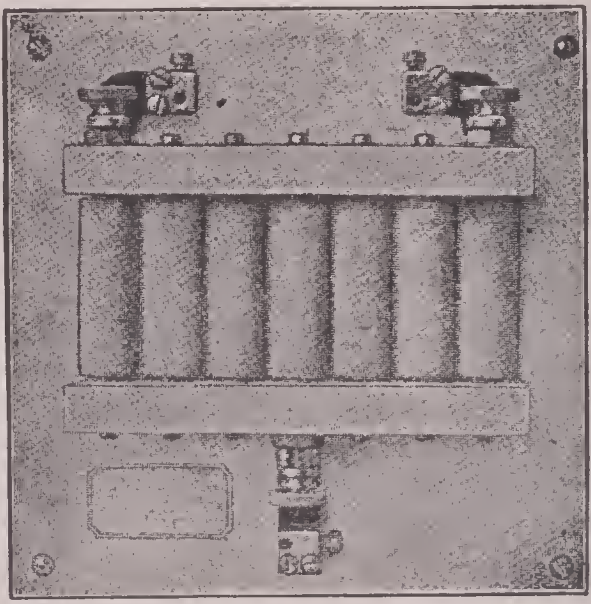


Fig. 37. Wurtz Non-arcing Lightning Arrester. Used with Alternating Current.

These cylinders are held in insulating strips so as to be about 1-64 of an inch apart. For low voltages the center cylinder is grounded and the end ones connected to the lines.

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*Abbreviation for alternating current.

When used on A C circuits the discharges which spark across do not cause arcs.

The probable reason is that the cylinders being close together, the spark makes a little explosion which blows the arc out, and the boiling of the metal where the spark jumps carries the heat away in the vapor and the spot is too cool to hold an arc.

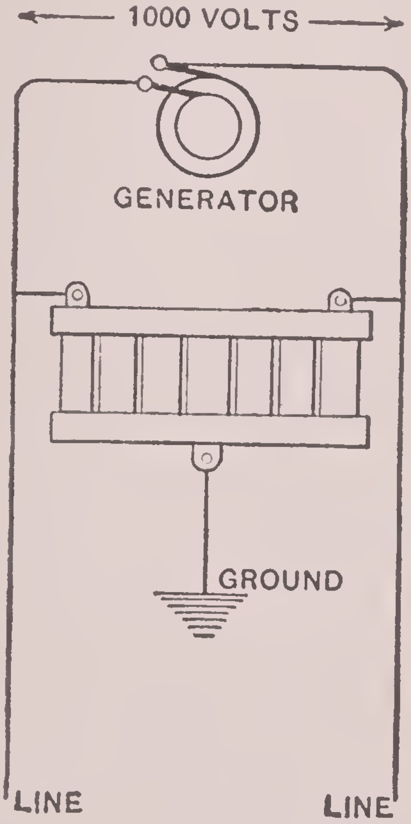

Fig. 38. Wiring diagram for 1000 volt circuits. One Arrester used.

The cylinders must be turned after each storm to present fresh surfaces for the next discharge.

A single arrester is shown in Figs. 37 and 38. Figs. 39 and 40 show the arrangements for higher voltages.

It will be noticed that this is of the multigap type.

[In Fig. 40 is shown the beginning of the "new idea" in lightning arresters which will be discussed at length further on.]

Question 20. How does the non-arcing arrester in Fig. 40 operate?

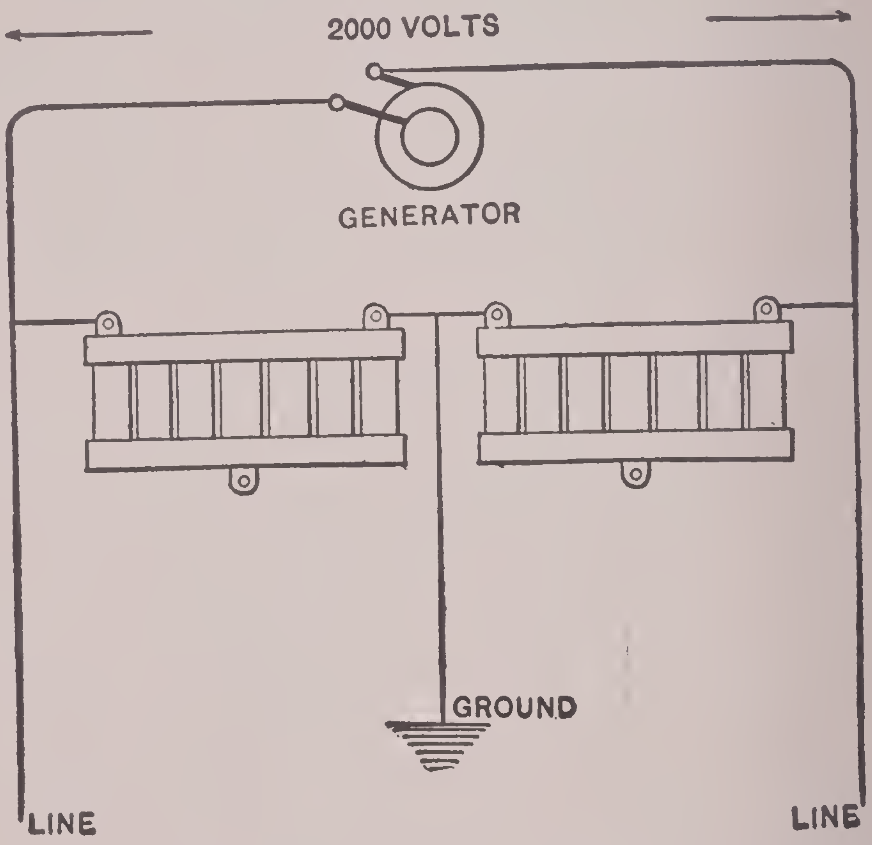

Fig. 39. Wiring diagram for 2000 volt circuits. Two Arresters used.

Answer. The operation of this arrester is as follows: The number of series gaps is adjusted to the voltage at which the arrester is desired to discharge. This is the real lightning discharger. The series resistance is small and so wound that it is as little like a coil in its choking action as possible. Its presence will prevent a large current flowing through the arrester while it is discharging.

If only as few series gaps as are shown were there, with a small series resistance, the dynamo current which follows the lightning discharge will cause an arc and burn the cylinders.

When shunted gaps are used the result is:

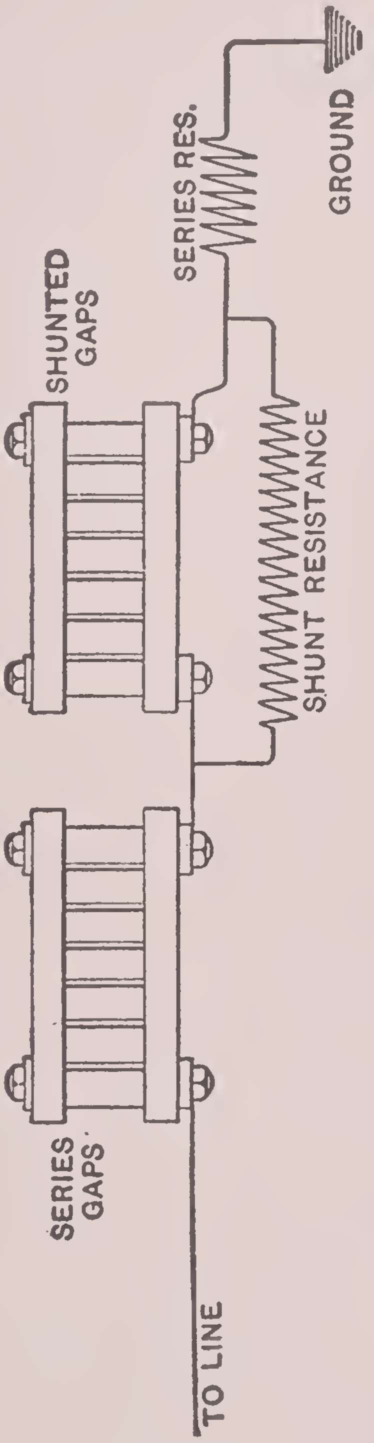

Fig. 40. Arrangement of Arresters and Resistances for High Voltages. This forms a Multigap Arrester.

The lightning followed by the line current passes through the series gaps. Then the lightning due to the choking action of the shunt resistance, sparks through the shunted gaps, while the line current on account of the high resistance of the shunted gaps, passes through the shunt resistance.

There is then no line current in the shunted gaps to hold an arc. The lightning having now discharged the line current finds a series circuit, composed of the series gaps, the shunt resistance and the series resistance.

The shunt resistance being large, the total resistance of the arrester is large enough to shut off the line current entirely.

Had such a large resistance been in series with the series gaps at first the arrester would not have started to discharge and of course afforded no protection.

Question 21. Is there a non-arcing direct current arrester?

Answer. Yes, the non arcing direct current arrester is based on these facts.

(1) Lightning will pass over a non-conducting surface more readily than across an equal air gap.

(2) It will pass even more readily if the surface is covered with carbon.

(3) An arc cannot form where there is no air to help the material burn.

A lignum-vitæ block is charred in its center for about half an inch in width. Two metal plates are set flush in the block on each side of the charred strip.

A second block is screwed tightly over the first to keep out the air.

This arrester works on direct current up to 700 volts. The lightning passes easily from plate to plate; while the charred strip of about 50000 ohms resistance prevents the passage of current from the line.

The lightning cannot start an arc in this small space.

One plate is connected to a line wire and the other to the ground. Two should be used, one on positive wire and the other on the negative.

These arresters have been used with "smooth cored" alternating current generators furnishing 1000 volts pressure.

Question 22. Is there a small, cheap arrester for single instruments and small buildings, as switch men's cabins, tool houses, etc., and for use on electric light circuits?

Answer. Yes. A lightning arrester designed for alternating current (abbreviated A. C.) up to 350 volts pressure is shown in Fig. 41.

Where long secondaries are run from transformers, a necessity has been found for the use of lightning arresters. The demand for a low priced but effective and reliable arrester for this service has resulted in the arrester shown.

This device is for use on any A. C. circuit of 350 volts or less, and is suitable for protection of individual series A. C. arc lamps, as well as on incandescent lighting circuits. Its effectiveness when placed on wires at the entrance to buildings, store-houses, signal towers, etc., recommends its general adoption.

A detailed description of construction is given later. The general plan is shown in Fig. 41, where will be seen the two large circular discharge plates separated by an air-space of 1/50 (.020) inch at their beaded edges. Over this air-gap a heavy discharge may pass, while light discharges and static surges will pass to earth, more slowly, through the high resistance disc that separates the larger metallic discs. This disc is of permanent resistance and allows the passage of but an infinitesimal normal current, while permitting the escape of the high voltage static discharges. In the event of the discharge being heavy, it will jump the spark gap, but the low voltage of the normal current will not maintain an arc, owing to the cooling effect of the heavily beaded disc.

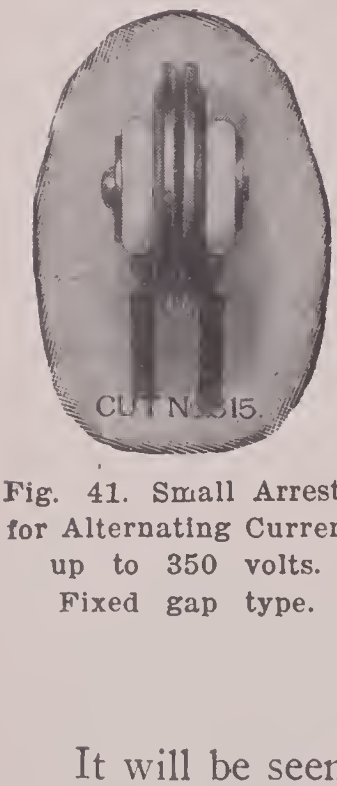

Fig. 41. Small Arrester for Alternating Current up to 350 volts. Fixed gap type.

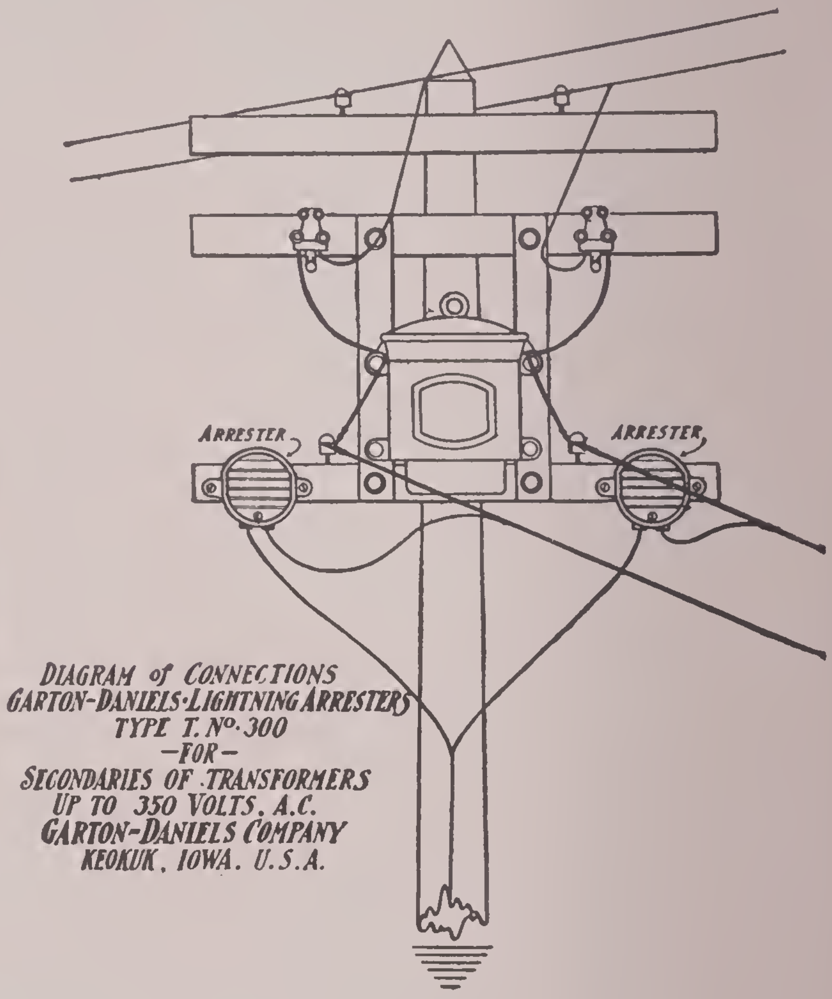

Fig. 42.

It will be seen that this device offers a choice of either of two paths, one highly efficient as an outlet for static surges, and the other (the spark-gap of 1/50 inch) a highly efficient path for lightning discharges.

When used on the secondaries of transformers, one arrester is necessary on each leg of the circuit. Same should be connected in a shunt path to earth as shown in Fig. 42.

As an arc lamp protector it is connected directly across the terminals of the lamp as shown in Fig. 43, thus offering a path around the lamp, to the standard pole arresters, which should be distributed along the line at intervals. These standard pole arresters are, of course, connected between line and ground, and thus offer an easy escape for the discharges.

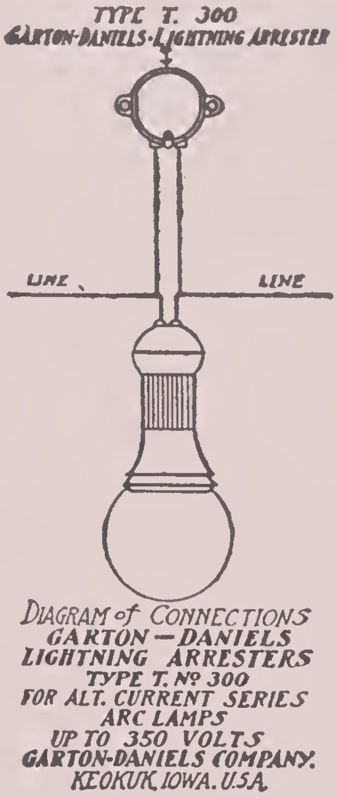

Fig. 43.

It has been customary in many cases to use standard forms of arresters in the same service for which this device is designed. These standard forms have the objection of higher cost, larger size, and, as all employ a much greater spark-gap distance, are not nearly so efficient as this Type T. arrester. Furthermore, the auxiliary path through the high resistance disc increases the efficiency of this arrester many times, The device consists of the parts illustrated in Fig 44 assembled as shown in side view Fig. 41. Parts Nos. 309 are two metallic discs, formed with a heavy bead around the circumference, the center being flat to make contact with the high resistance disc, No. 311. These parts are assembled on the insulating tube, 312. The high resistance disc separates the metallic discs so that the heavy beaded circles are separated by 1/50 (.020) inch. Parts Nos. 308 are insulating discs, also mounted on 312. The screw, No. 306, passes through steel washer, 307, tube, 312, and asbestos disc, 313, so as to clamp them together when screwed into weather-proof box, 302. The flexible leads, No. 310, pass through porcelain insulator, No.

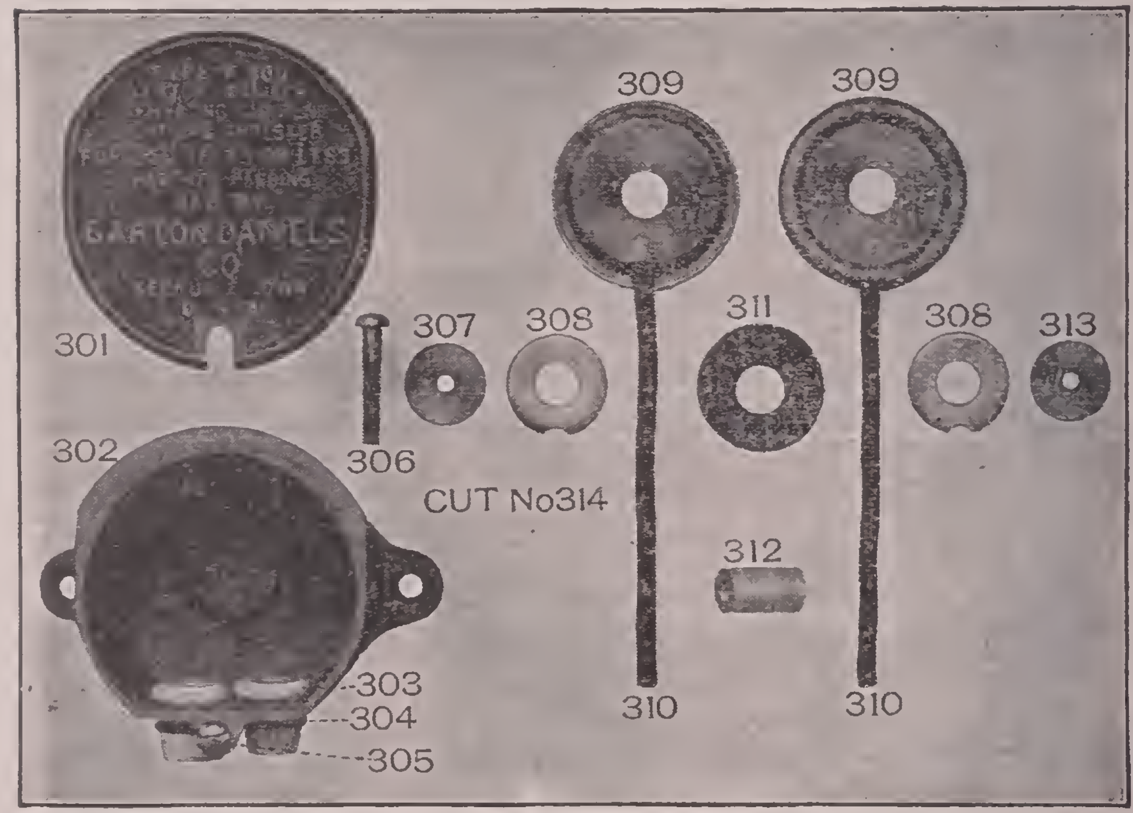

Fig. 44a. Parts of Arrester shown in Fig 41.

303. The cover, 301, hooks over the top of box, 302, and is fastened in place by but one screw, 305. This cover is perfectly weather-proof. Complete, the arrester measures 3½ inches from center to center of supporting holes.

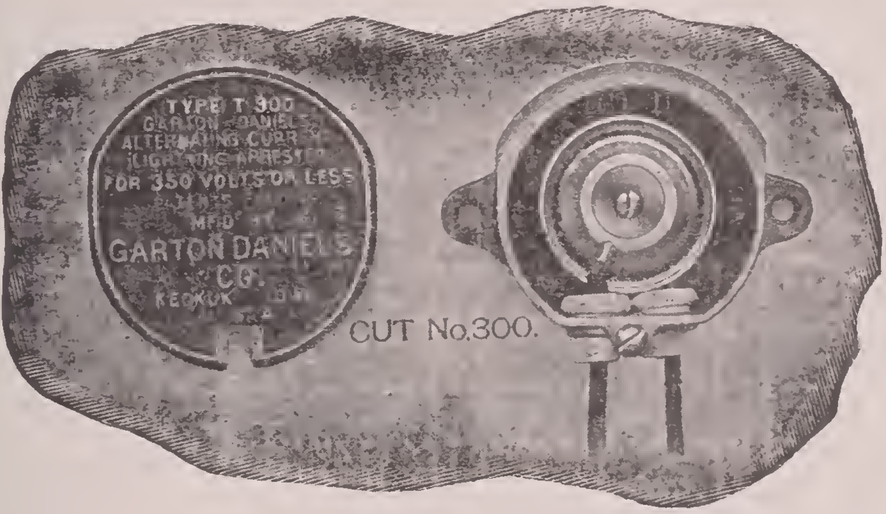

Fig. 44b. Arrester parts as shown in 44a assembled ready to screw cover on.

Protection of Lines.

Question 23. How should signal lines be protected?

Answer. When on pole lines an arrester should be placed on pole about every half mile; when run in conduits or tunnels one should be placed at each end of conduit or tunnel.

Question 24. How should telegraph lines be protected?

Answer. As the instruments are only placed in stations, an arrester at point where wires enter station is sufficient.

Question 25. How should telephone lines be protected?

Answer. A protector which contains a "sneak current" device should be placed in every line where it enters a building.

Question 26. How should feeders to trolley wire or third rail be protected?

Answer. Such lines are usually fairly short and not much exposed to lightning being carried on low poles. The arrester on the feeder at the station and one where the feeder connects to trolley or third rail should give ample protection.

Question 27. How should trolley wires or third rails be protected?

Answer. The arresters at the ends of the feeders ought to be sufficient for the trolley wire also.

If there are very few feeders it would be well to see that there is an arrester every half or three quarters of a mile. One to the mile will do, as trolley construction is very strong and not liable to damage.

The third rail lies along the ground and is seldom struck. If it were the mechanical strength of the rail itself and its insulators would protect them, although the lightning did side flash to the ground.

Question 28. What protection should motor cars or locomotives have?

Answer. There should be an arrester in the main circuits which furnish the power, and an arrester in the control circuits which control the motors. These two arresters should be of different styles. That for power circuits should discharge at 1,000 volts and that in the control circuits at 250 volts.

Question 29. What protection should be given to a trolley car?

Answer. An arrester should be placed on roof or under hood of such a capacity that there can be no chance of its failing to operate.

LESSON 8.

LIGHTNING ARRESTERS.

HIGH VOLTAGE.

An arrester of the two gap type with a magnetically lengthened gap to break arc is shown in Fig. 45, and its construction in Fig. 46. It is made for alternating or direct current work.

In order to increase the surface distance, so as to prevent breakdown between current carrying parts of considerable difference of potential, one of the discharge points is mounted on the end of the resistance rod B. This rod is held in position by the clamps at C and D. The distance from clamp C to upper discharge point A is 2¾ inches. The solenoid cut-out coil H is supported by brackets I and K, bracket K being so designed that it gives a surface distance on the porcelain base of 2¼ inches between K and lower discharge point bracket L. This is a total of 5 inches, which is a liberally safe surface distance on porcelain for 2500 volts.

To still further reduce the possibility of current jumping between parts, the line connection is at the top of the Arrester, from which the discharge passes downward in a practically straight path to ground connection. This path is indicated by the round dots in Fig. 46, the dashes showing the path of the normal current. It will be noted that the discharge goes through the section of the resistance rod C-D, the normal current being shunted through the solenoid coil H. This energizes the iron armature J, which raises upward in the coil, opening the circuit between the discharge point M and lower end of armature. The discharge point M is stationary, so that the air-gap at N is not changed by the operation of the Arrester. The arc is thus drawn out until broken inside the tube, which is practically air tight and prevents flying sparks or serious arcing. The upper end of discharge point M is car-

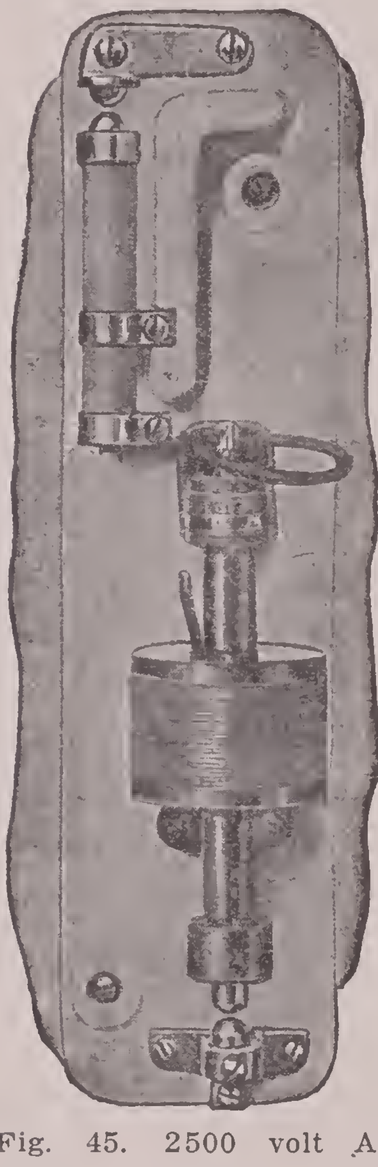

Fig. 45. 2500 volt Alternating Current Arrester. Mechanically lengthened gap type.

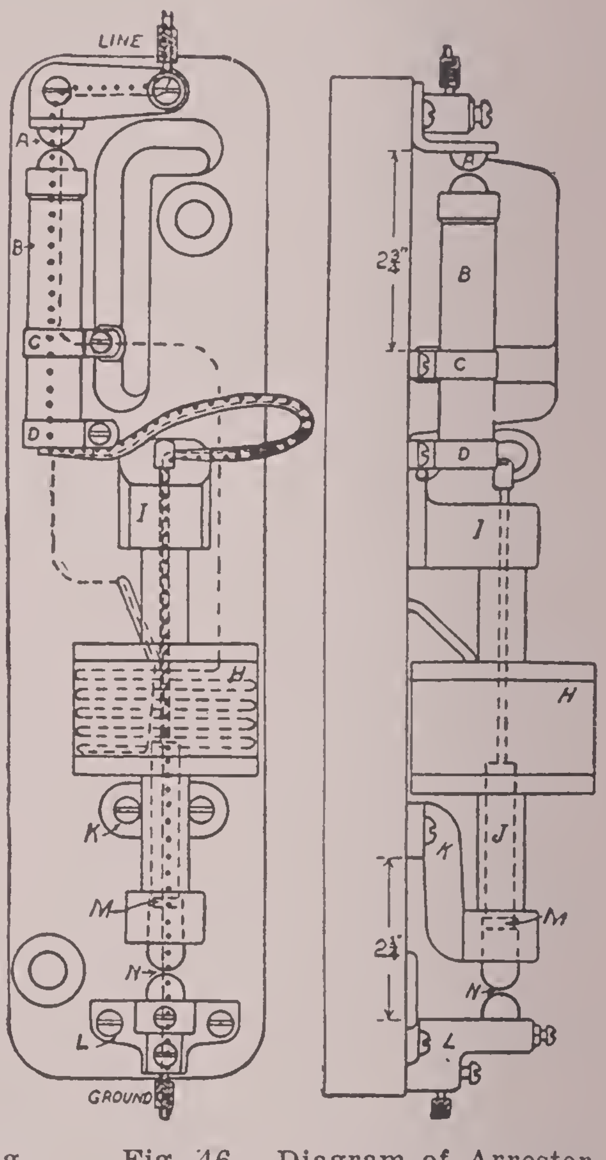

Fig. 46. Diagram of Arrester shown in Fig. 45.

bon, so the arc is drawn out between the same and the iron armature. This combination prevents sticking or welding together.

3500 volt arresters are designed along the same lines as the 2500 type. They differ in width and length of base to accommodate the higher voltage rating per arrester unit. In the 3500 volt arresters is provided an additional air-gap near the line binding-post. This construction has proven in extended service to be perfectly safe, and satisfactory for the higher voltage rating of 3500 volts.

As the circuit is opened inside the tube and the air-gap adjustment is always the same, it is possible to use the small air-gap space. In this 2500 volt arrester, the air-gap distance is 3-32 inch, which is as small as can be used safely.

The cut-out is entirely automatic, restores itself by gravity, is instantaneous in operation, and prevents grounding the line, whether the discharge points are dirty from repeated operation or not. If the normal current follows the lightning over the air-gaps, it is shunted through the coil. The coil immediately cuts it off and the normal dielectric of the air-gap is restored.

To limit the flow of normal current that can follow the discharge to ground, the upper section of the resistance rod B is employed, there being approximately 250 ohms between discharge point A and clamp C in the 2500 volt arrester. This keeps the current down to a value that is broken readily by the cut-out, and is not enough resistance to impede the passage of the discharge.

This feature is particularly effective where a part of the circuit is grounded, or where the circuit is temporarily or accidentally grounded. This series resistance prevents a heavy short-circuit through the arrester. The cut-out

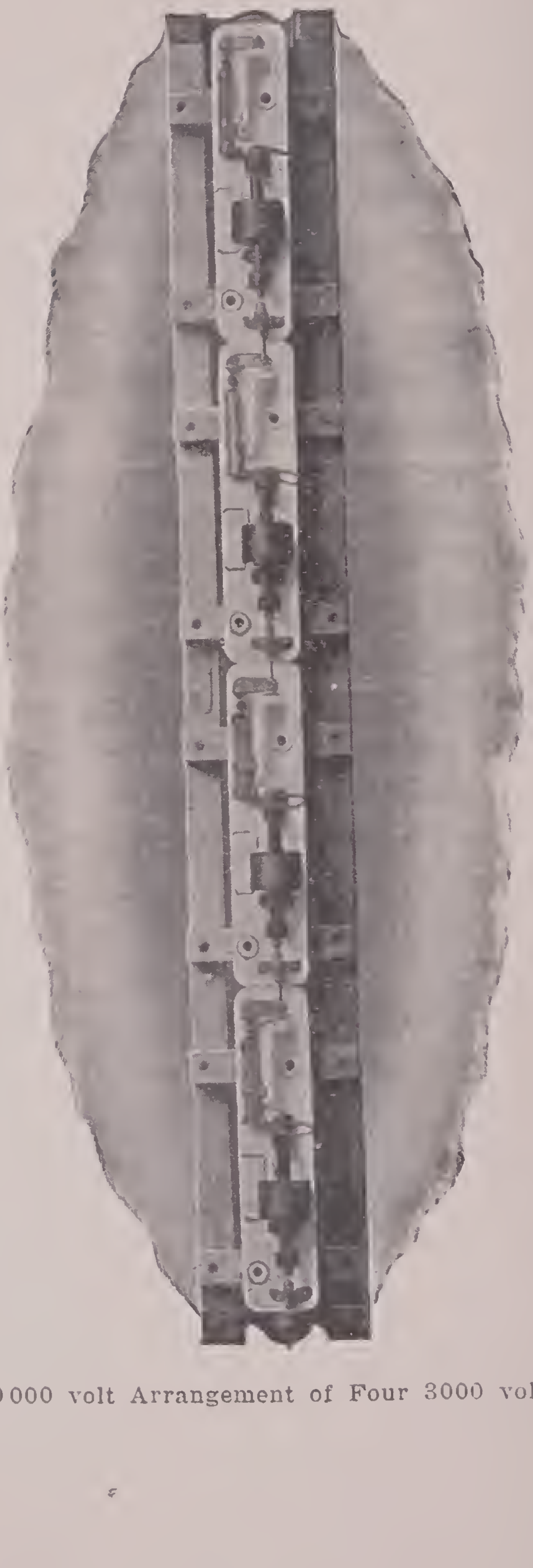

Fig. 47. 10000 volt Arrangement of Four 3000 volt Arresters.

readily interrupts the flow of normal current, and the arrester is again ready for another discharge.

The positive action of the cut-out renders the arrester independent of the condition of the discharge points, and they require no more than an occasional inspection.

When protection for higher pressures is desired a number of these arresters are often mounted in series as shown in Fig. 47.

The multigap arrester with graded shunt resistance for alternating current.

If a series of knurled cylinders of zinc alloy about 1/64 of an inch apart has the first one connected to a line and the last one grounded, there will be an electric strain all along the series due to the tendency of the pressure on the line to force electricity through the series to the earth.

Suppose a single gap between two cylinders will always prevent 400 to 600 volts from jumping across, but that 800 volts will be sure to jump.

Suppose you have a 22000 volt line and place 56 cylinders in line making 55 gaps, each gap will stand 400 so the 22000 volts will never spark across.

Suppose a lightning discharge increases the pressure on the line to 33000 volts, which makes 600 volts per gap. One would think that the gap will not be jumped, and that the insulation of the machines, etc., will be strained. The frequent occurrence of this will finally break down the insulation and a burnt out generator be the result.

However, an arrester of a large number of gaps works in a peculiar manner.

When the normal 22000 volts is on the arrester the first gap has a pressure on it of 600 to 700 volts and each successive gap less and less on to the end.

The pressure does not distribute itself evenly over all the gap but piles up on the first few.

It is clear then that when the abnormal 33000 comes on the line that the first few gaps of the arrester have a pressure of 900 to 1000 on them, and the spark jumps across.

The state ot affairs is now as if 52 gaps were placed as an arrester on a 31500 voltage. The first few gaps getting the highest pressure are sparked across.

This action takes place all along the 55 gaps, each gap nearest the line being sparked across by the concentration of pressure upon it, until all the 55 gaps are sparking. The discharge passes to the earth and the line is relieved.

Another peculiar thing now happens. When all the gaps are sparking the voltage distributes itself evenly over the arrester; so that now only 600 volts are across each gap and the sparks go out before any of the current of the line can flow through and cause arcs.

If line current should follow the lightning discharge this current by its action brings the arrester more quickly to the even distribution state, and the arcs go out.

If the discharge did not completely relieve the line a second one would immediately occur, or a succession of them until the pressure was down to 22000. At that pressure there would be 600 to 700 volts on the first gap and very little on the last.

It is evident that in designing a multigap arrester you cannot divide the line voltage by 400 and put in that many gaps in series and be positive that 22000 volts won't discharge through it under all conditions of regular use.

You must remember that extra gaps are needed as you increase the number in the arrester. Three gaps will hold 1200 volts while 120000 volts will go right through 300 gaps. Ten times as many gaps will not hold back ten times the pressure.

This arrangement of a large number of gaps called the multigap arrester has three excellent features.

(1) It will discharge at a very slight increase of pressure above the normal.

(2) It automatically stops discharging when pressure on line falls to nearly the normal pressure.

(3) Line current going through the arrester carries its own cure.

This condition of high pressure existing at the end of a series of gaps may be illustrated by connecting ten incandescent lamps (110 volt type) suddenly to a 1000 volt circuit. There will then be a surge which will generally burn out a lamp or two at each end of the series. Those lamps at the center of series will never be damaged.

Remember this is not a proof of the high pressure at the first gaps because the lamps are broken by a surge, but it does prove that pressures can pile up at a point in a circuit far above normal, and makes one willing to believe that the gaps might do a similar thing.

The objection to the multigap arrester is as peculiar as its action.

A static discharge is of low frequency and a lightning stroke discharge of high frequency.

A high frequency pressure causes a greater pressure on the first gap than a low frequency pressure.

Hence, an arrester discharges at a lower pressure for lightning-stroke, than for static accumulations.

If then enough cylinders are used so that the regular voltage on line won't break* down the gaps, there will be often static accumulations of higher voltages than is safe for line but of such low frequency that enough pressure will not be exerted on the first gap to start the arrester into action.

It is the multigap arrester with graded shunt resistances that solves this problem.

Low frequency pressures can only break down a few gaps as compared with a high frequency pressure of same voltage.

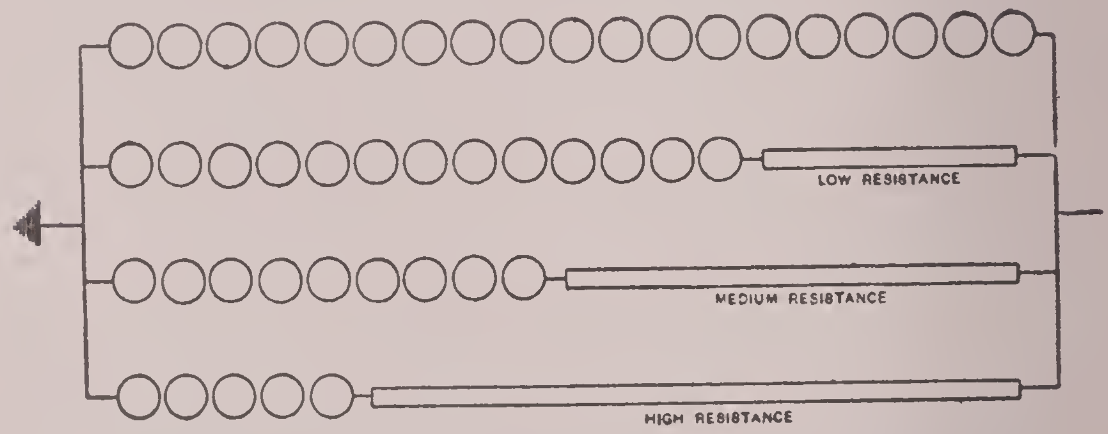

Fig. 48. Diagram of a Multigap Arrester in Imperfect Form.

Suppose as in Fig. 48 there are arranged between line and ground four circuits, one of 18 gaps, another of 12 gaps and a low resistance, a third of 8 gaps and a medium resistance, while the last has 4 gaps and a high resistance.

It will be seen that the opposition offered by any of the four circuits to 6600 volts will be perfect and no line current will pass through the arrester.

A lightning stroke of high frequency will pass through the 18 gaps quite easily. Surges will perhaps be unable to pass the 18 gaps, the frequency being too low, but will find their way through one of the other circuits. Static accumulations being of very low frequency will pass through the 4 gaps and high resistance while they could not get through any of the other three. Remember that any of these must be above the normal pressure to discharge. In fact, unless they were above normal voltage we would not care about them.

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*The words "break down" used with lightning arresters do not mean any damage to apparatus but merely refer to the discharge.

The objection to this arrangement of gaps and resistances is that a static charge of very high pressure and very low frequency might occur.

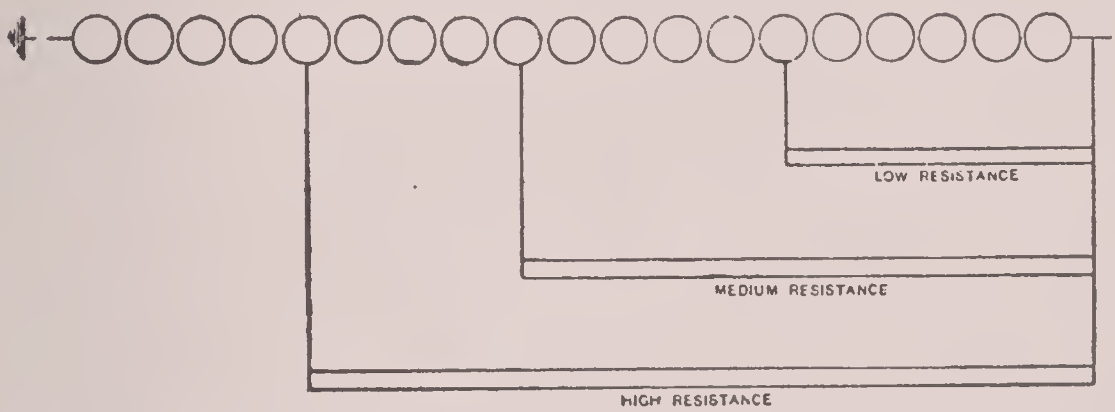

Fig. 49. Perfected Form of Multigap Arrester with Graded Shunt Resistances.

This could only break down the 4 gap high resistance leg* of the arrester on account of low frequency. It would discharge so slowly through the high resistance that the line would not be freed from the high pressure quickly enough to prevent damage.

The arrangement of gaps and resistances actually used is shown in Fig. 49. The multigaps are put in series and the three resistances are put in as shunts.

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*Parts of circuits which have the same starting and ending points are often called legs.

This removes the objection just mentioned and incidentally uses far less cylinders in an arrester.

The action is just the same, each frequency selecting its own path. In addition to this each time the arrester acts no matter what the frequency, the whole line of gaps from end to end breaks down and relieves the line quickly.

In fact, with this arrangement we might say that the resistances are merely a device to enable a low frequency to break down more gaps than it usually can.

This action takes place as follows: When a low frequency discharge passes through the high resistance and sparks across the last 4 gaps; at the same time, part of it passes through the medium resistance, and as the last 4 gaps are sparking it is able to break through the 4 in front of it to them. This action occurs all the way up the arrester.

The action can also be explained in this way: The low frequency pressure passes through the three resistances and exerts its pressure at different points along the gaps. At only one place does it find few enough gaps between itself and the ground. This place is the last 4 gaps. It breaks these down and begins to discharge to earth. But now at the end of the medium resistance connection it finds only 4 unbroken gaps, and is able to break them down and it does so.

In this way the whole arrester breaks down in sections, even for low frequency discharges.

In Fig. 50 is shown a 2300 volt arrester with two resistances and in Fig. 51 is shown a set of cylinders mounted on slate base. These sets of cylinders are used in building up the 6600 volt up to 60000 volt arresters.

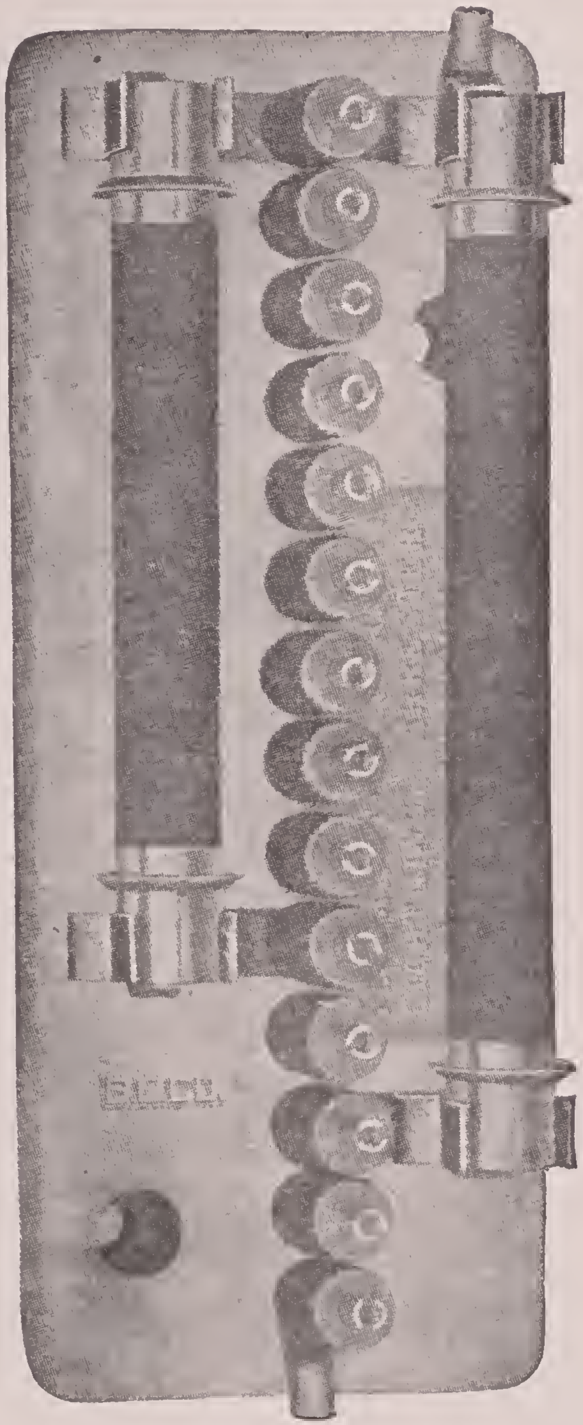

Fig. 50. A 2300 volt Multigap Shunt Resistance Arrester for Alternating Current.

With these high voltages a long spark gap shunted by a fuse is placed in series with the arrester. Then on a heavy short circuit the fuse blows and puts the spark gap in series with the arrester.

This prevents the destruction of the arrester and does not put it completely out of action. The fuse should be replaced as soon as possible. Frequent inspections should be made to see that cylinders are clean and the fuse in working order.

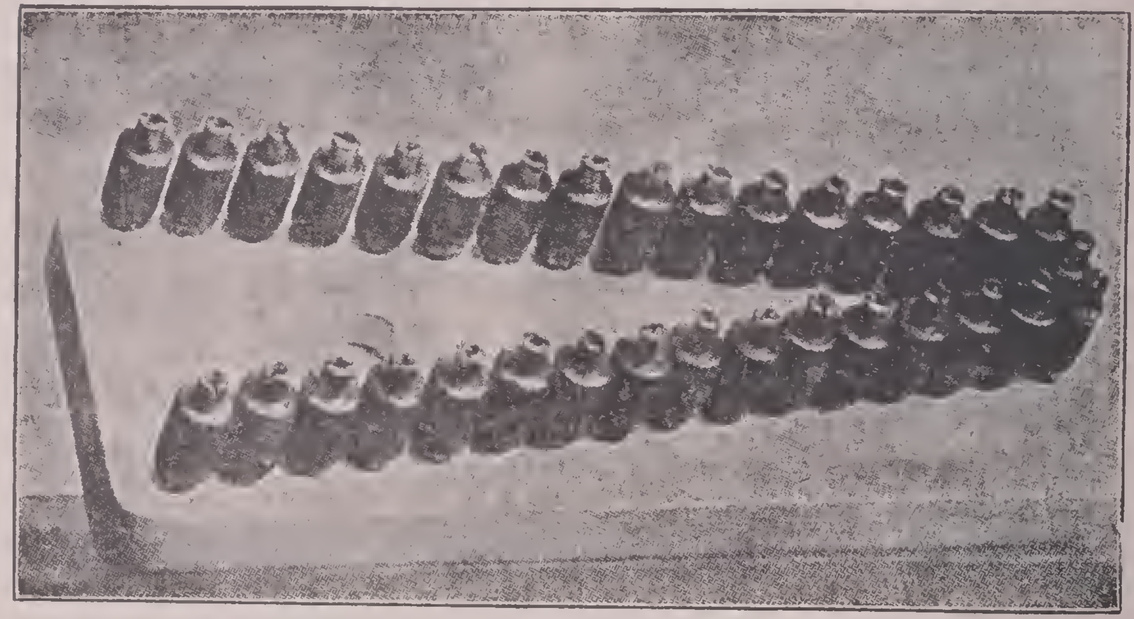

Fig. 51. Set of Cylinders on Slate Base. These are used as units to make up complete arresters.

PROTECTION OF LINES.

Transmission Lines.

Question 1. What is one of the simplest methods of protecting an overhead line?

Answer. Using a ground wire.

Question 2. What is a ground wire?

Answer. It is one or more wires strung parallel to the line and grounded at every pole. One is about as good as more and very much cheaper.

Question 3. In what position are they placed?

Answer. When there are two line wires one ground wire should be run on the top of the pole, or two ground wires run; one at each end of the cross arm or another cross arm below the main arm.

When there are three line wires, one ground wire should run on top of pole or in the center of the triangle formed by the line wires, or three ground wires should be installed, one on top of the pole and one at each end of a cross arm under the main cross arm.

Question 4. Why are they run on glass insulators?

Answer. They must be tied to something and a cheap glass insulator is less expensive than some special device which is not an insulator. The fact that the glass is an insulator is not harmful, because a ground connection is made by a wire at every pole.

Question 5. Are the ground wires copper?

Answer. They are usually galvanized iron about No. 4 size but a stranded 3/8 "cable" is better.

Question 6. Is the iron wire as good as copper for a ground wire?

Answer. Yes, for electrostatic charges the size of the wire is of far greater importance than the material.

Question 7. Barbed wire is generally used, is it not?

Answer. Formerly it was, but engineers are now believing that the plain wire is as good, and being cheaper and much easier to handle is much more used than the barbed.

Question 8. What was the reason for originally using barbed wire?

Answer. It was thought that the barbs acted as discharge points to let the free charges escape quickly into the air.

Question 9. Do they not act that way?

Answer. They probably would if the free charge was not neutralized by the earth connection so quickly.

A plain grounded wire well connected to earth is sufficient protection.

Barbed wire is not as strong as a plain wire of equal weight per foot.

Question 10. Why are not ground wires always put above the line wire?

Answer. They used to be put above, because engineers thought the ground wire was a protection from a direct lightning stroke.

We now think that they are not much use in that case, so do not always put them above so as to have them struck first.

We often put them below believing that, in the way that they protect, they can do so as well from there as from above.

Furthermore, being below should they break they cannot cause short circuits by falling on the line wires.

A single ground wire is often put on the top of the pole for convenience, but a single ground wire with three line wires is sometimes put in the center so as to be equally distant from all three.

Question 11. How does a ground wire protect the line?

Answer. It seems to be a fact that lines are not often struck by lightning, but that thunder or electrical storms affect the lines by static charges very frequently.

This is done as follows: A cloud heavily charged with say positive electricity blows up over the line. There will be induced in the line a bound negative charge and a free positive charge. This free charge will have a tendency to go to the earth. It may do so by leakage over and through the insulators of the line if the approach of the cloud is slow enough to allow it to do so, if not it jumps through the insulator puncturing it, or it may side flash over the insulators from wire to cross arm.

If a ground wire is present a bound negative and a free positive charge is induced in it.

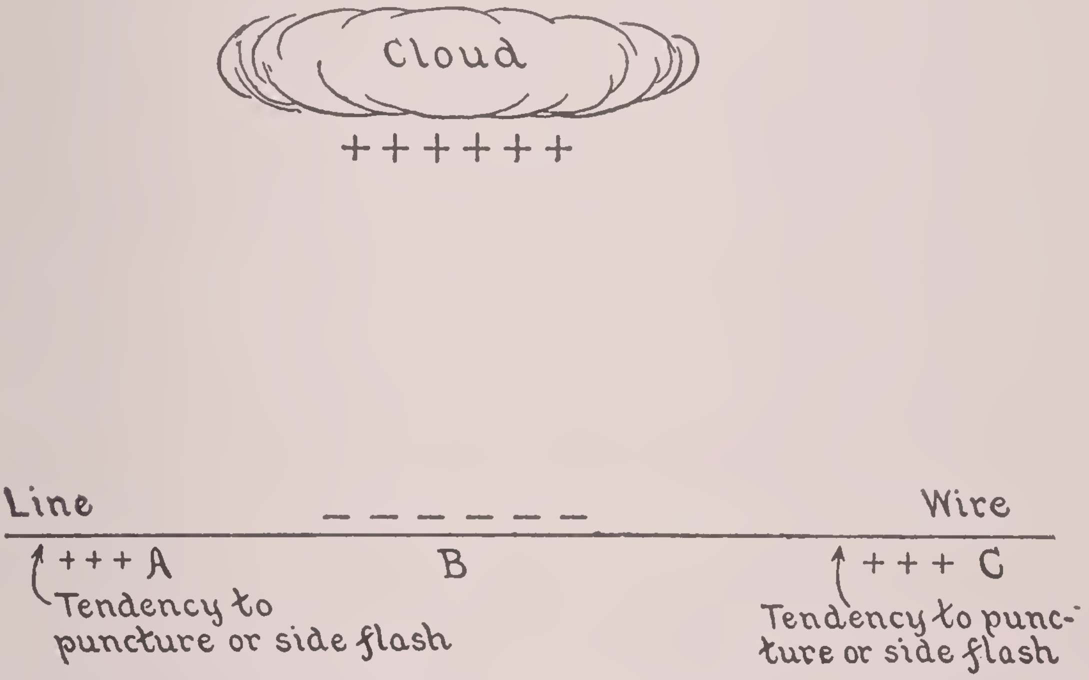
Cloud
++++++
Line
– – – – – –
Wire
+++ A
B
+++ C
Tendency to puncture or side flash
Tendency to puncture or side flash

Fig. 52. Electrostatic Charges on a Line under a Thunder Cloud Without a Ground Wire.

This bound negative charge prevents as great an electrical separation on the line as the cloud alone would make and so the line does not become so highly charged.

This is shown in Figs. 52 and 53.

In Fig. 52 suppose the cloud to cause an electrical separation in the line as shown. There will be a tendency to puncture or side flash at points A and C.

Now suppose the charge on the cloud to be neutralized by a lightning flash from cloud to earth. If it does not strike the line at B and neutralize the negative charge there, it will leave this charge free and there will be a tendency to puncture or side flash at B. After this the charge at A and B will spread over the line with a surge.

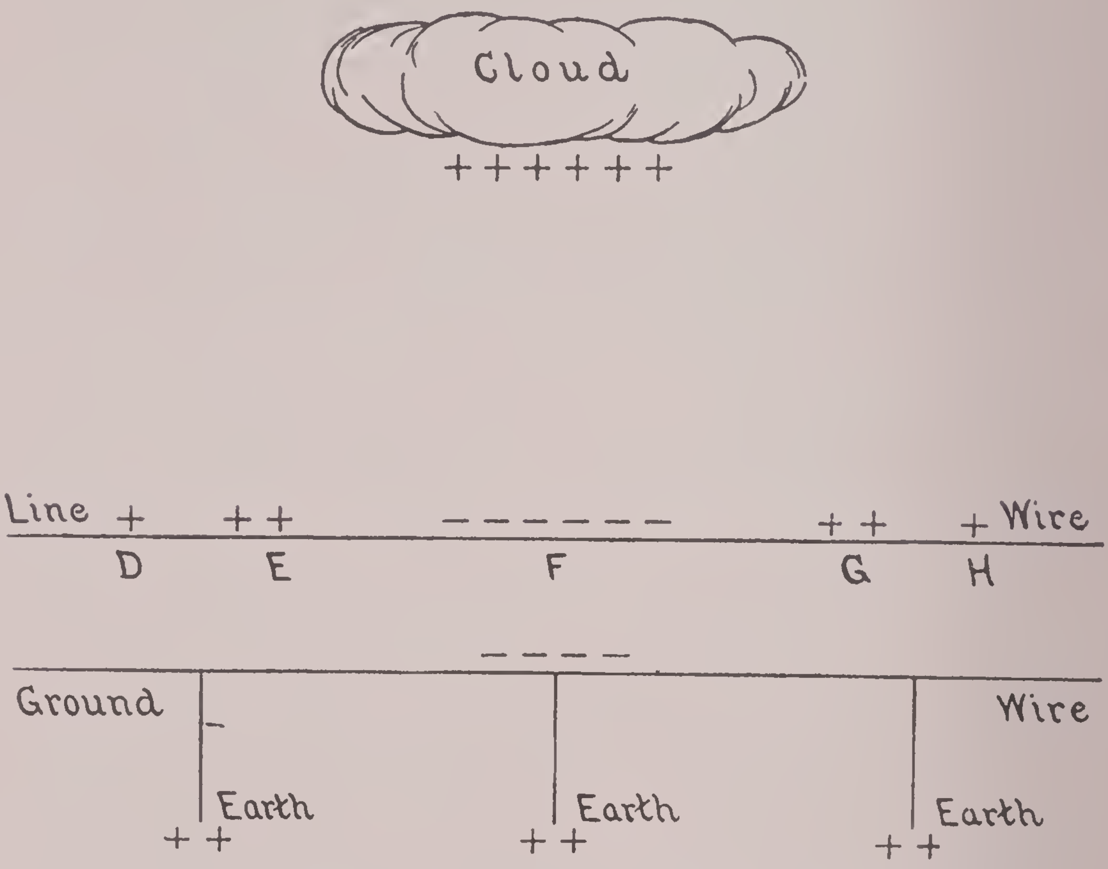

Fig. 53. Electrostatic Charges on a Line having a Ground Wire.

When the ground wire is there as in Fig. 53 the cloud induces a negative charge on the ground wire which is smaller than that on the line. It is smaller because the capacity of the ground wire is less than that of the line wires. It would be far too expensive to make the ground wire capacity nearly equal to the line itself.

The free positive charge on the ground wire goes to earth and the bound negative charge acts inductively on the free positive charge of the line. This causes the distribution of charge to be as is shown and the tendency to have static troubles at E and G is less than it would be without the ground wire.

Suppose now the cloud is discharged. The charge at F on line will not act as violently as that at B did, because the repelling effect of the negative charge on the ground line at F tends to spread out the negative charge on the line at F. Thus the tendency to static discharge at F is less than if ground wire were not there.

Question 12. What are the objections to a ground wire?

Answer. It is expensive to install. It is only a partial protection and other devices must be used with it.

Question 13. What is its chief value?

Answer. It prevents the splitting of the poles, and damaging of insulators.

Question 14. Does it protect the station?

Answer. No, it is a line protection.

Question 15. What other simple protectors are there?

Answer. The horn arrester is an extremely simple device.

Question 16. What is a horn arrester.

Answer. A horn arrester is as shown in Fig. 54. A single spark gap whose length is regulated by the pressure it is designed to withstand (say 6¼ inches for 90000 volts) has a wide spreading pair of horns attached, the ends being perhaps twelve feet apart.

Question 17. How are they attached to line?

Answer. One side is attached to a line wire and the other side of gap is grounded. A fuse is placed in the ground wire. Each line wire has its own horn.

Question 18. How do they work?

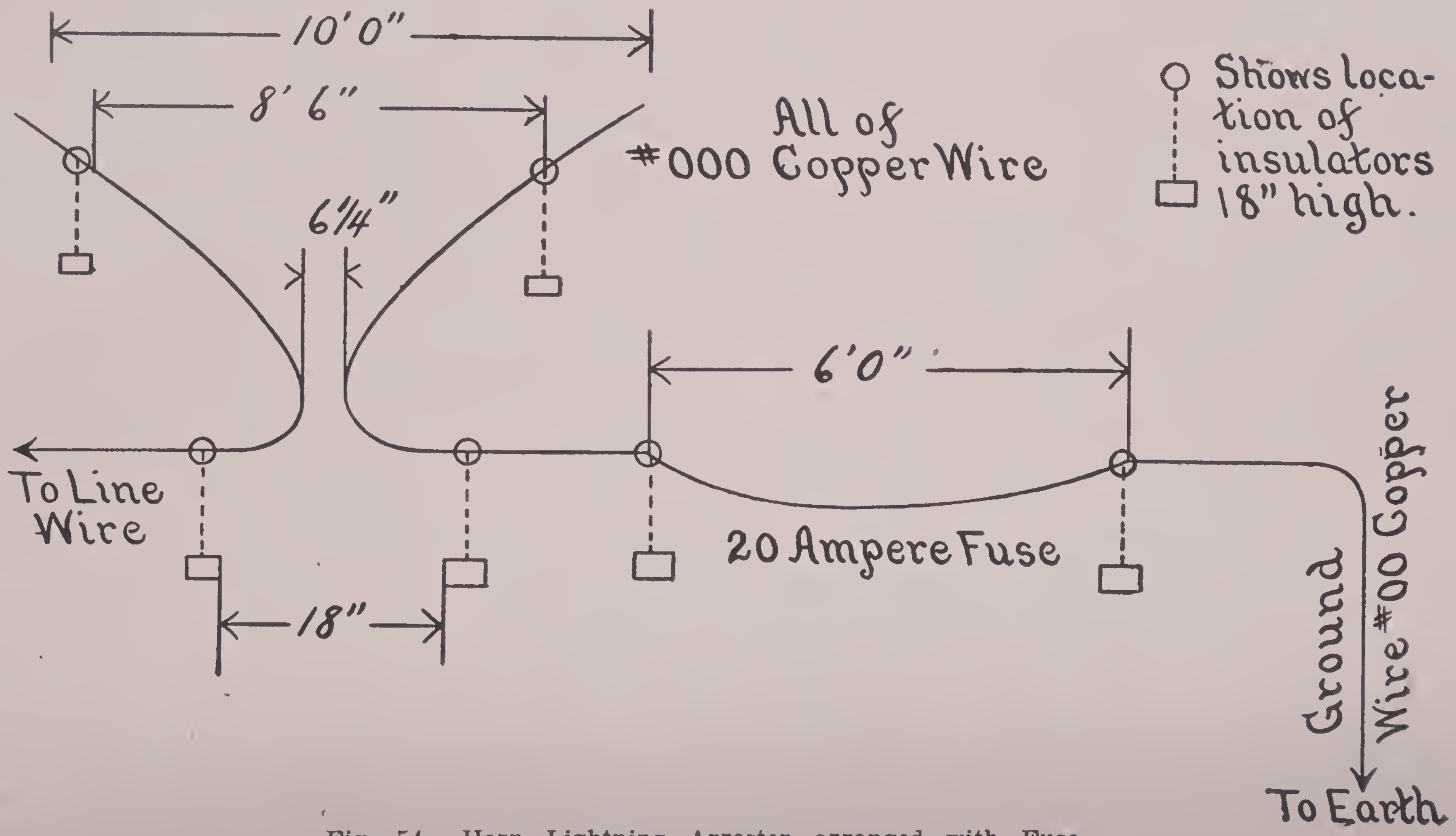

Fig. 54. Horn Lightning Arrester arranged with Fuse.

Answer. The discharge jumps across the gap forming an arc. The heat of the arc causes it to rise and as its ends are in the horns it is stretched out long and thin. This cools the arc down and it goes out. While the arc holds the charge on the line runs across it to the earth.

If the arc does not go out the normal current on the line flows across the arc and blows the fuse. The fuse is made very long so that an arc cannot jump across between the terminals which hold it.

Question 19. What are the advantages of the horn arrester?

Answer. Fairly cheap. They cannot get out of adjustment and discharge at wrong pressure. They cannot produce an accidental ground by getting out of repair or through defects in manufacture. They are mechanically strong and will stand the most severe strokes.

Question 20. What are the objections?

Answer. Any time they discharge the line the fuse may blow. The arrester is then useless until fuse is replaced.

The discharge is a vicious arc which sends a surge through line.

Some engineers think the surge is worse than the original trouble.

Question 21. What is the general opinion about them?

Answer. That they are an excellent thing to use at points on the circuit especially exposed to lightning.

Question 22. What are single or side horns?

Answer. As shown in Fig. 55, the ground wire of each pole is extended up beyond the top insulator and a branch run up outside of each side insulator.

This construction is to protect the insulators by allow-

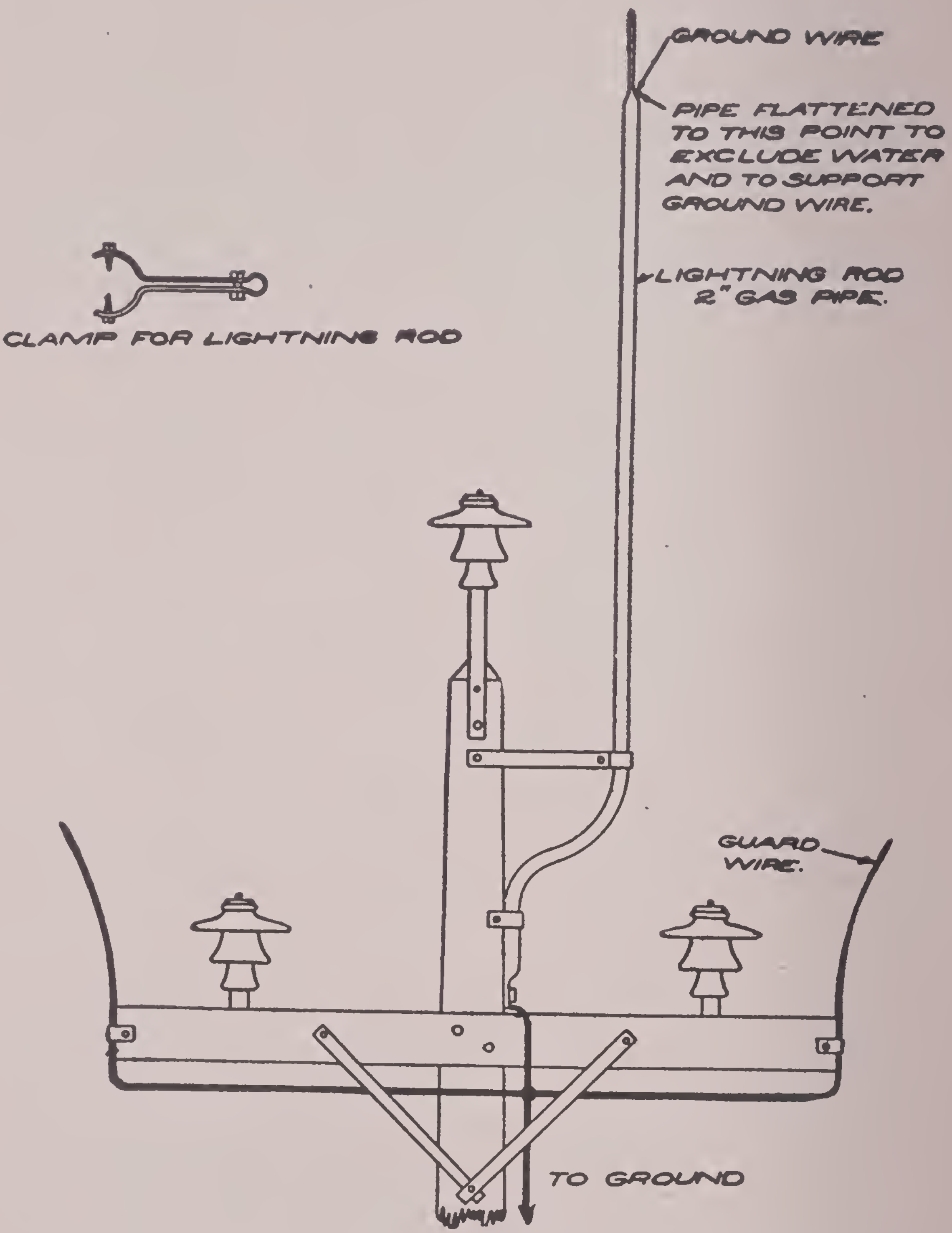
GROUND WIRE
PIPE FLATTENED TO THIS POINT TO EXCLUDE WATER AND TO SUPPORT GROUND WIRE.
CLAMP FOR LIGHTNING ROD
LIGHTNING ROD 2" GAS PIPE.
GUARD WIRE.
TO GROUND

Fig. 55. Side Horns.

ing the discharge to jump to the ground wire instead of flashing around insulator to the cross arm.

This Fig. does not show a ground wire strung from pole to pole.

But horn arresters and side horns can be installed whether there is a line ground wire or not.

Side horns are installed at every pole.

Question 23. What is the lowest voltage used on transmission lines?

Answer. 22000 volts, because at lower voltages the wires have to be so large that expense is too great.

MAINS, FEEDERS.

Question 24. What is the highest voltage used on mains and feeders?

Answer. 11000 volts. Any voltage higher than this needs such special protection, that it should be run on a high pole line, off to one side of the right of way.

The mains from power house or the feeders from substations to the third rail or trolley wire can be run at 11,000 with safety.

Question 25. How should mains and feeders be protected?

Answer. When on pole lines an arrester every half mile is the best practice. When underground, one at each end of the section.

Question 26. Are choke coils used with these line arresters?

Answer. No. Choke coils are only used with station arresters.

Unless an arrester is protecting machinery or instruments no choke coil is used.

LESSON 9.

LIGHTNING ARRESTERS.

AUXILIARY APPARATUS.

Question 1. What is a choke coil?

Answer. It is a coil specially designed to insert in a line between the apparatus to be protected and the lightning arrester.

Question 2. How are they made?

Answer. For low voltage they are simple coils of insulated wire mounted on a slate bases as shown in Fig. 56.

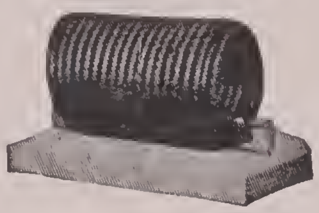

Fig. 56. Low Voltage Choke Coil.

For high voltage (over 600) the wire is bare and the turns are wound in an hour glass fashion, so that air forms the insulation between turns.

Question 3. How do choke coils act?

Answer. A surge or stroke encountering a choke, reactive, or kicking coil in its path is momentarily held back,* practically stopped. The coil then begins to conduct the charge. It will be seen that the choke coil offers protection for an instant only, but during this time the arrester on the line side of the coil can free the line of the charge.

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*Throttled, choked off, kicked back, are some of the terms used.

The damming up of the surge by the choke coil produces an enormous pressure which helps to force the charge through the arrester.

Question 4. What is the objection to a choke coil?

Answer. It has resistance, and so wastes energy, it will also retard a little the flow of the normal current. In order to prevent their interference with normal operation they are large and expensive.

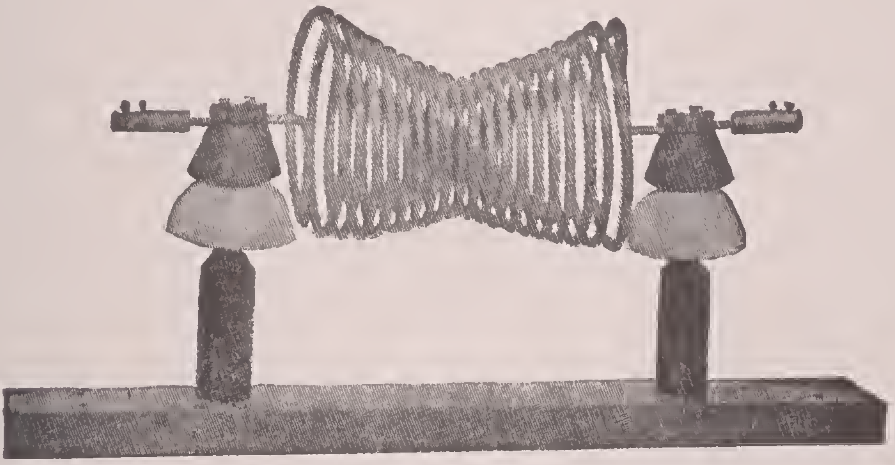

Fig. 57. Hour glass Type of High Voltage Choke Coil.

Question 5. What are the advantages?

Answer. They increase the protection offered by the arrester and even if arrester fails to act the choke coil protects to some extent by causing a side flash on the line where damage is less expensive than should it occur in the station.

Question 6. How are lightning arresters installed?

Answer. They are placed in between line and ground and the two arresters which are attached to the line wires at a certain point are all connected to the same ground wire, so that there may be a free discharge between line and line, as well as between line and ground.

Question 7. What precautions must be taken when installing arresters in buildings?

Answer. The National Electric Code gives the following rules for the construction and installation of arresters in buildings:

1. Lightning arresters must be mounted on non-combustible bases, and must be so constructed as not to maintain an arc after discharge has passed, and must have no moving parts.

[The arrester shown in Fig. 45 has been tested and approved by the National Board of Fire Underwriters although it has a moving part.]

2. Must be attached to each side of every overhead circuit connected with the station.

It is recommended to all electric light and power companies that arresters be connected at intervals over systems in such numbers and so located as to prevent ordinary discharges entering (over the wires) buildings connected to the lines.

3. Must be located in readily accessible places away from combustible materials, and as near as practicable to the point where the wires enter the building.

Station arresters should generally be placed in plain sight on the switch-board.

In all cases, kinks, coils, and sharp bends in the wires between the arresters and the outdoor lines must be avoided as far as possible.

4. Must be connected with a thoroughly good and permanent ground connection by metallic strips or wires having a conductivity not less than that of a No. 6 B. & S.

copper wire, which must be run as nearly in a straight line as possible from the arresters to the earth connection.

Ground wires for lightning arresters must not be attached to gas-pipes within the buildings.

It is often desirable to introduce a choke coil in circuit between the arresters and the dynamo. In no case should the ground wire from a lightning arrester be put into iron pipes, as these would tend to impede the discharge.

Question 8. How should arresters be grounded?

Answer. For station arresters there are many ways of getting a good ground.

Copper sheets approximately 1/8 inch thick and of 4 to 6 square feet surface are suitable. A piece of cast iron of large surface, with brass or copper plug tapped into it for connections, is preferable. Cast iron does not waste away as rapidly, and, when completely oxidized, still affords a good ground path.

The ground wire must be carefully riveted or soldered to the plate and the connection coated with a preservative paint.

The plate should be buried deep enough to be in damp soil the year through. The bottom of the hole should be covered with broken charcoal, coke or carbon to a depth of 2 or 3 inches. After the plate is put in position, it should be covered with another layer of charcoal, coke or carbon, and the hole filled with earth. It is well to use running water to settle.

Ground connections may be made to plates placed in the mud at the edge of a stream. Where water or gas pipes are available, the ground wires should be soldered to a brass plug screwed into the pipe in addition to the connection with the ground plate provided. In grounding arresters on electric railway circuits, a connection with the rails, as well as with the ground plate, should always be employed.

Where an iron pipe is used to protect the ground wire, the wire should be soldered to a cap on the upper end of pipe. This avoids the choking effect of the pipe upon a wire passing through it.

For pole arresters a cheaper arrangement is necessary. The ground pipe is perhaps the best.

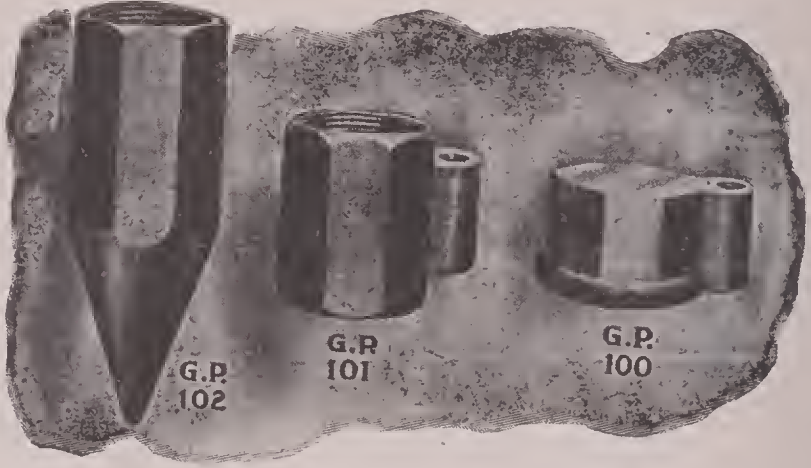

Fig. 58. Ground Pipe Fittings.

These may be driven into the earth, or if the soil will not permit driving, a hole may be dug at the foot of the pole to receive same. The pipe should extend upward along the pole for eight to twelve feet above the ground, to prevent cutting or removing the wire, and the ground wire soldered to a cap on the upper end of the pipe. The pipe should extend eight or ten feet below the surface where it will be in damp earth the year round.

For this purpose are manufactured the fittings illustrated in Fig. 58. These are tapped for use with ¾ inch iron pipe and consist of the brass cap GP 100, with lug for soldering in ground wire from the arrester. GP 101 is a brass coupling for connecting upper and lower sections. (It being more convenient to drive an 8 or 10 feet length and then couple on another length, than to drive a 16 or 20 feet length.) This brass coupling GP 101 is also provided with a lug for soldering in wire to rail, when used on electric railway circuits. The driving point GP 102 is of malleable iron, with dipped galvanized finish.

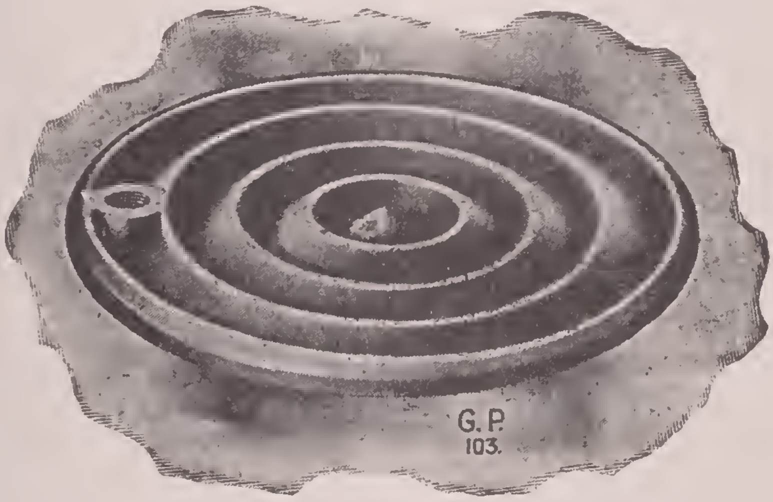

Fig. 59. Ground Plate for Pole Arresters.

The pipe may be driven by placing an iron cap on upper end, to protect the threads, or the method used by well-drivers may be used to advantage. This is to start the hole, fill with water and "churn" the hole to the required depth with the pipe. This method is of particular advantage where the soil is very hard.

In Fig. 59 is shown a cast iron plate, 12 inches in diameter (total surface 450 sq. in.), with hole near edge tapped for ¾ inch pipe. This plate may be used in place of the driving point and should be buried at the foot of pole, and the necessary length of pipe attached.

It may be buried at the bottom of pole before the pole is set, but if this is done, it should be made certain that the surrounding soil will be damp the year through.

In electric railway circuits the rails should be connected to the ground wire as is shown in Fig. 60.

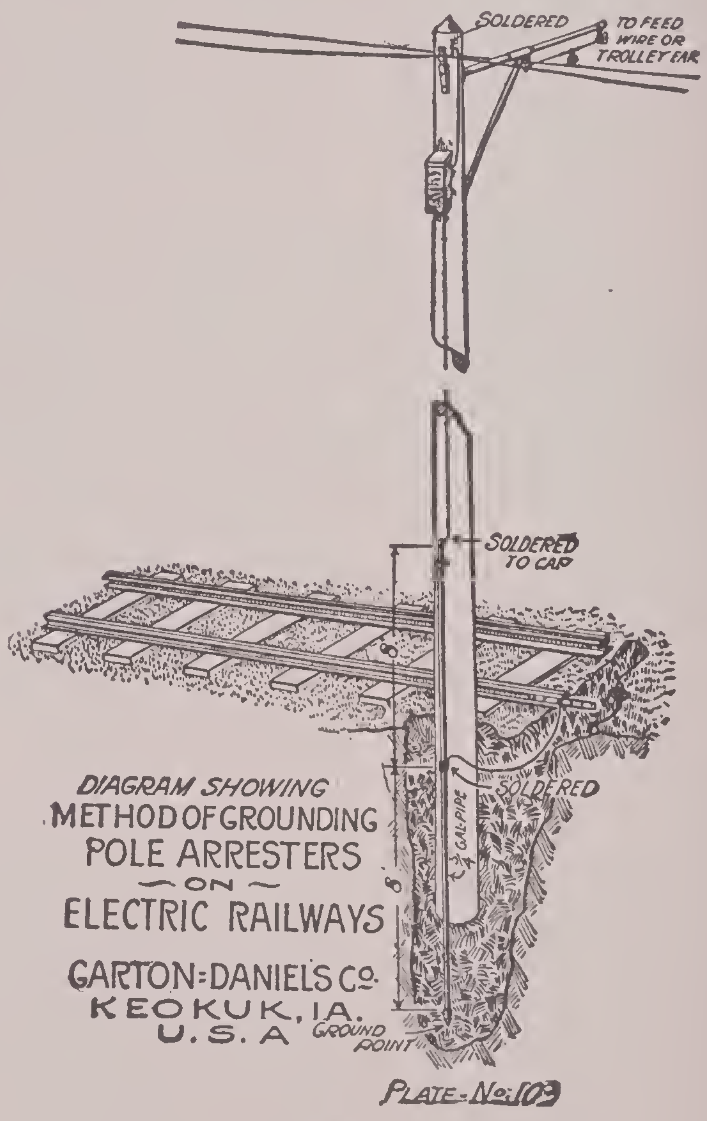

Fig. 60.

The rail alone will not suffice, as it may be up on a rock road-bed, or buried in cement or a soil that does not provide a low resistance path for the lightning. With a connection to both rail and ground point, any danger due to difference of static potential between rail and earth is avoided. Should either one of the connections be broken or fail from any cause, the other one probably will be in order and afford a degree of protection.

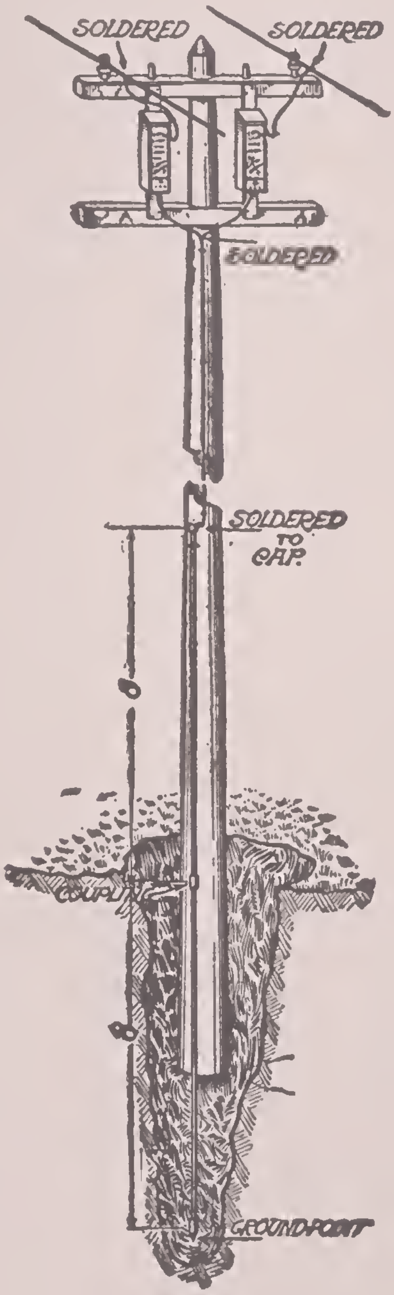

Fig. 61.

Fig. 61 shows manner of grounding a two wire or ungrounded circuit.

All ground wires should be No. 6 gauge or larger.

Question 9. What inspection is necessary for lightning arresters?

Answer. Frequent inspection (once a month) and cleaning with a bellows for dust is necessary.

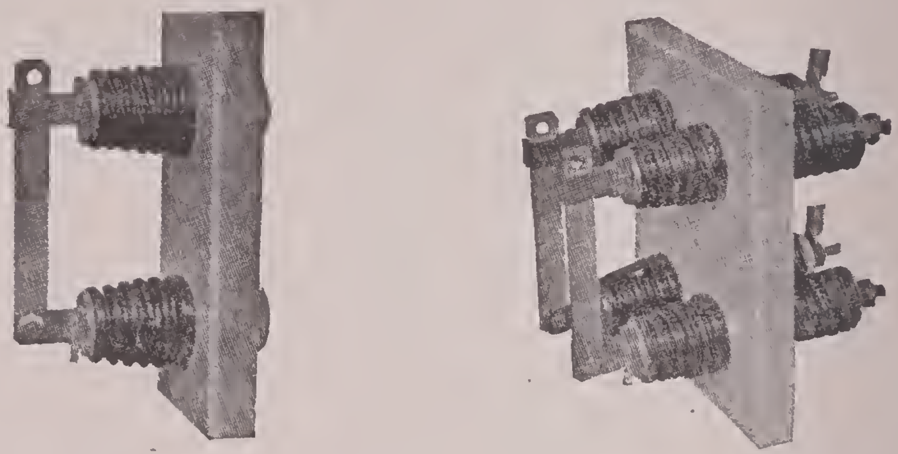

Fig. 62. Low Voltage Arrester Disconnecting Switches. Single for Railroad work. Double for Electric Lighting.

Question 10. Is there not danger in the men inspecting the arresters?

Answer. Disconnecting switches as shown in Figs. 62 and 63 are installed in places where some other switch will not serve to disconnect the arresters.

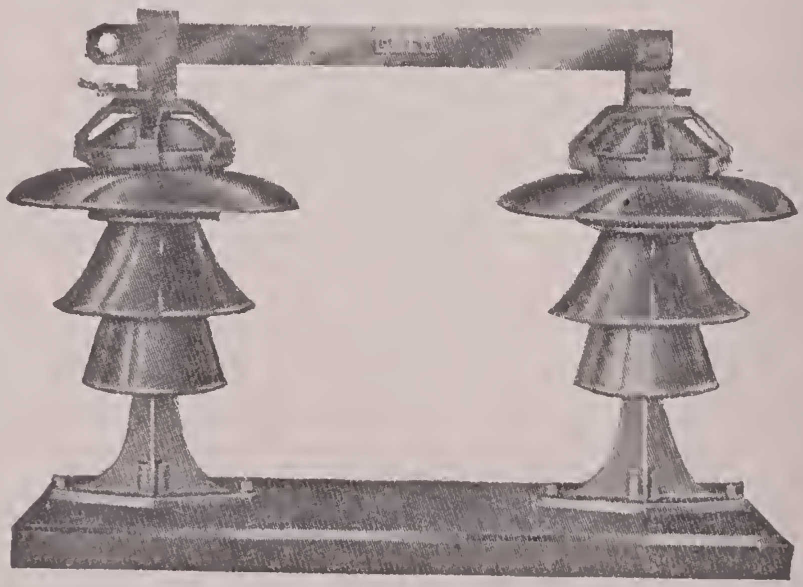

Fig. 63. High Voltage Disconnecting Switch for Arrester.

LESSON 10.

MAGNETISM.

INTRODUCTION.

The natural magnet has been known for ages. The Egyptians and Greeks in their writings long before the Christian era mentioned that a certain mineral attracted iron and steel. They also knew that a piece of steel being rubbed or rather stroked with the mineral, acted just as if it had become a piece of the mineral. Fig. 64.

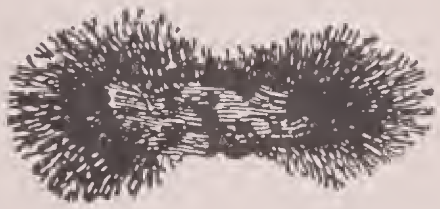

Fig. 64. Natural Magnet: A piece of Magnetite or Black Oxide of Iron.

Who first discovered that the mineral would point to the north, we do not know, but in the year 1200 A. D. Arabs brought compasses to Europe.

The mineral was called lode stone because it was a leading stone i. e. it lead you to the north.

The name magnet was also given to it because most of it came from a part of Greece called Magnesia.

Besides the quantity in Greece large quantities of magnetite are found in Sweden, Spain, also in states of Arkansas and New Jersey.

Question 1. What is a magnet?

Answer. A magnet is a piece of material which will turn into a north and south position when suspended so as to be free to turn.

Question 2. Can it be any material?

Answer. No. It can only be of iron, steel or nickel, or a few other substances which are feebly magnetic.

Question 3. But the mineral mentioned is a magnet?

Answer. Yes, because it is iron ore.

Question 4. Then copper, zinc, etc., cannot be magnetized?

Answer. No.

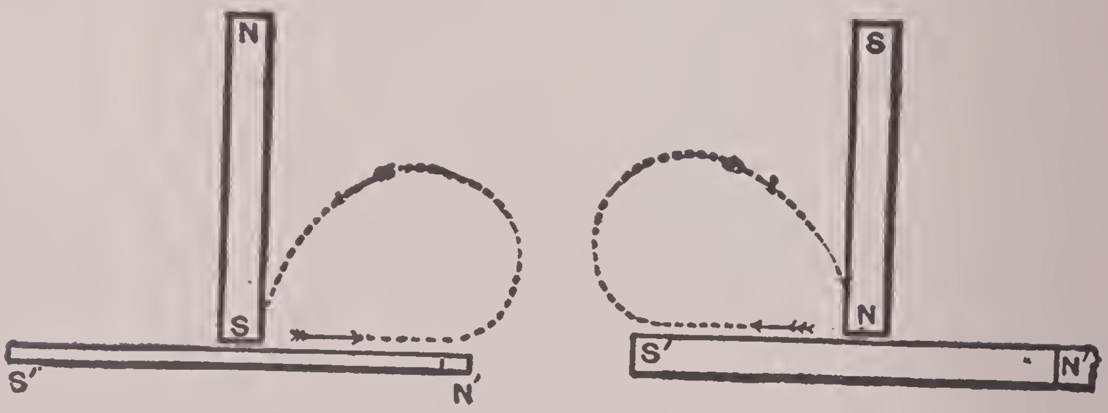

Fig. 65. Making a Magnet by use of a Permanent Magnet.

Question 5. How can a magnet be made?

Answer. Produce two pieces of Jessup's steel about 6x¼x¼ or 12x1x3-16 inches. Machinery steel, manganese steel, and some cast steels are useless. Heat them moderately bright red and plunge sidewise and edgewise into water or oil. They will become very hard and brittle, or as we say "glass hard."

1. Lay one down on the table and stroke one-half of the bar from the center out to the end. Fig. 65. Do this ten times with the S-pole of a permanent magnet,

and turning the bar over repeat this on the same end. You now have an N-pole. Then using the N-pole of the magnet stroke the other end of the bar in the same manner. You now have the complete magnet with two strong poles. You have made 40 strokes in all and you need that many, but sitting there stroking for a 100 or more times is wasted energy, for the bar soon becomes saturated and will take up no more magnetism. Then treat the second piece in the same way. Always make two at the same time and keep them by laying them with an N and an S-pole at the same end of the box, separating the magnets lengthwise by a strip of card board, and placing a strip of tinned iron or strap iron across the ends. Laid away separately or with two N-poles side by side they lose strength. Fig. 66.

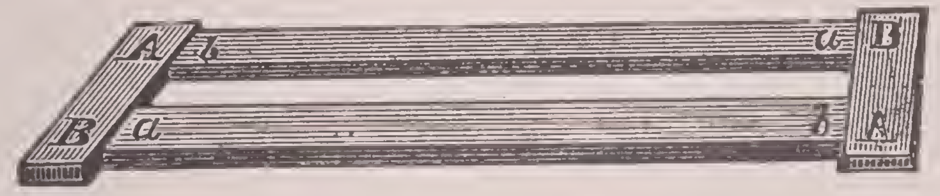

Fig. 66. Two Bar Magnets with Keepers across ends. A represents north pole and B, south pole.

As shown in Fig. 67 wrap insulated wire around the bar or on a spool in which the bar will be placed. Connect the wire to a battery, dynamo or electric light circuit, and while the current is flowing in the coil tap the bar with a hammer. Stop tapping before the current is turned off. No one unskilled in the handling of electrical machinery should do this, as one can cause considerable damage to himself and to the electrical wiring. Correct management of this process will produce the strongest possible magnet.

Question 6. Do magnets need to be handled carefully?

Answer. Yes. Dont: Heat, drop hammer, or file your magnet, for it will lose strength.

Question 7. How should magnets be kept when not in use?

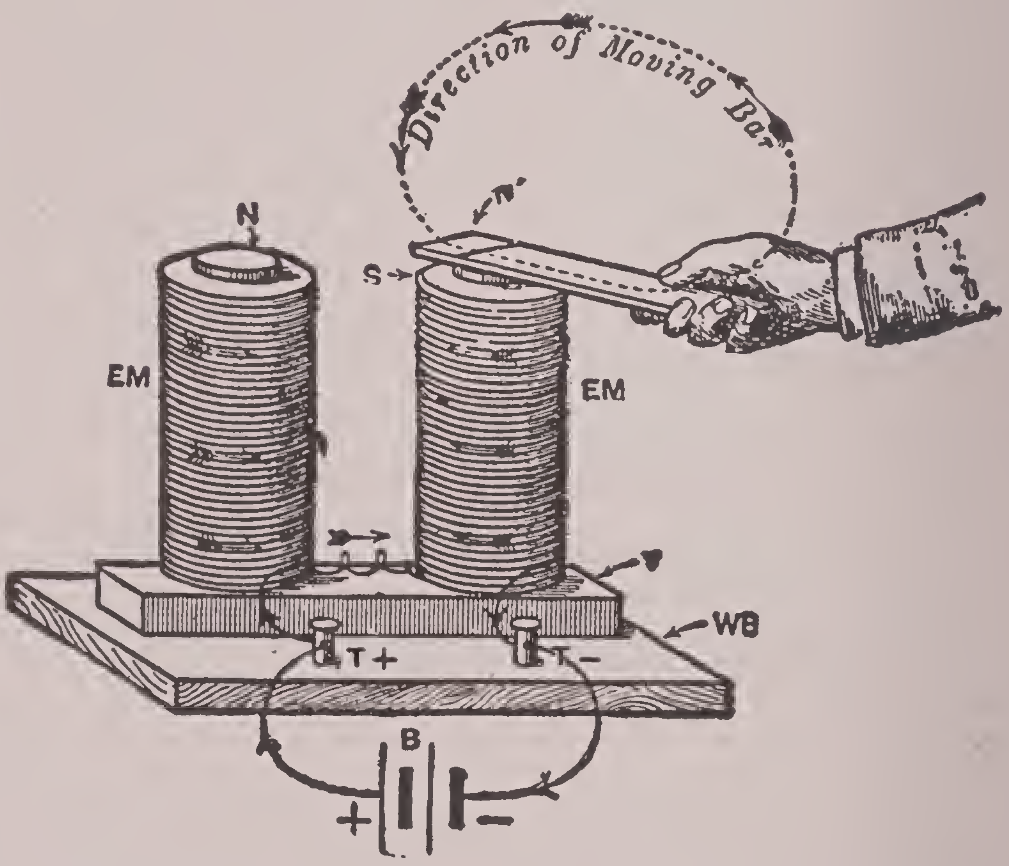

Fig. 67. Making a Magnet by means of an Electro-magnet.

Answer. Bar magnets should be laid side by side, separated by a thin strip of wood, the north end of one and south end of the other at same end. Strips of iron should be laid across the ends so as to touch both magnets as in Fig. 66.

Horse-shoe magnets should have a strip of iron laid across the ends as in Fig. 68.

Question 8. What is a magnetic needle?

Answer. It is a long slender magnet, as compared with its own width and thickness, fitted with a cap in the center so that it may be balanced on a pivot or hung from a thread. This allows it to turn freely. Fig. 69.

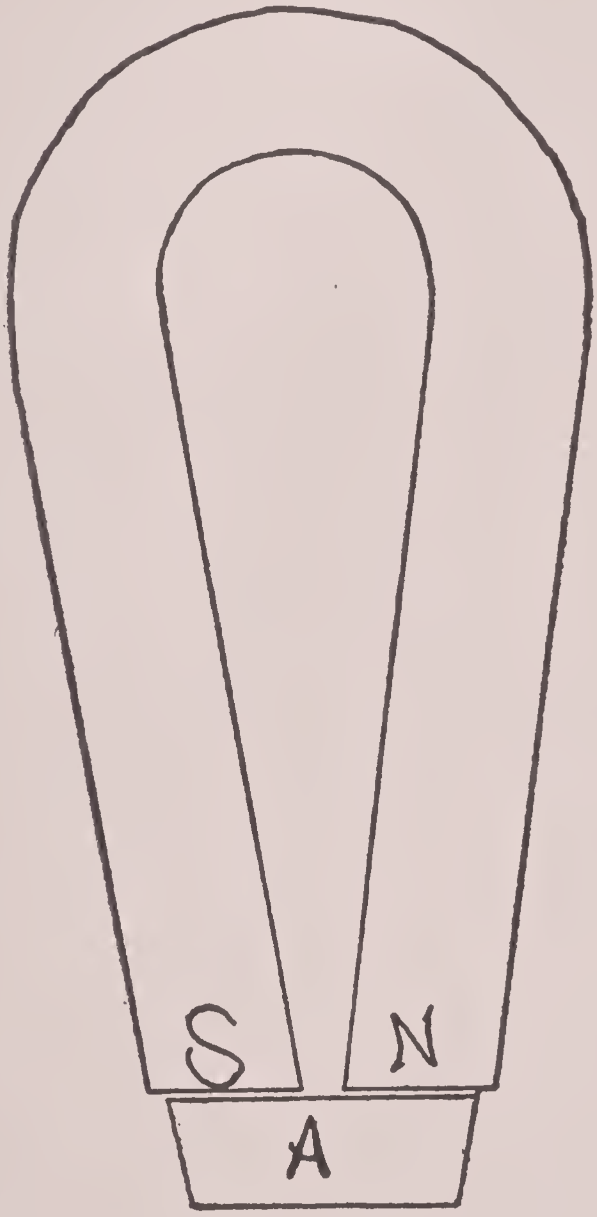

Fig. 68. A Horseshoe Magnet with its Keeper or Armature A.

Question 9. How may you determine whether a bar is a magnet or not?

Answer. To decide the question whether the bar in our hand is a magnet or not we put it to test in this way.

Remember, however, that should the bar be of wood, fibre, copper, zinc, etc., there is no need of a test since only steel, iron and nickel have enough magnetism in them to be worth calling magnets.

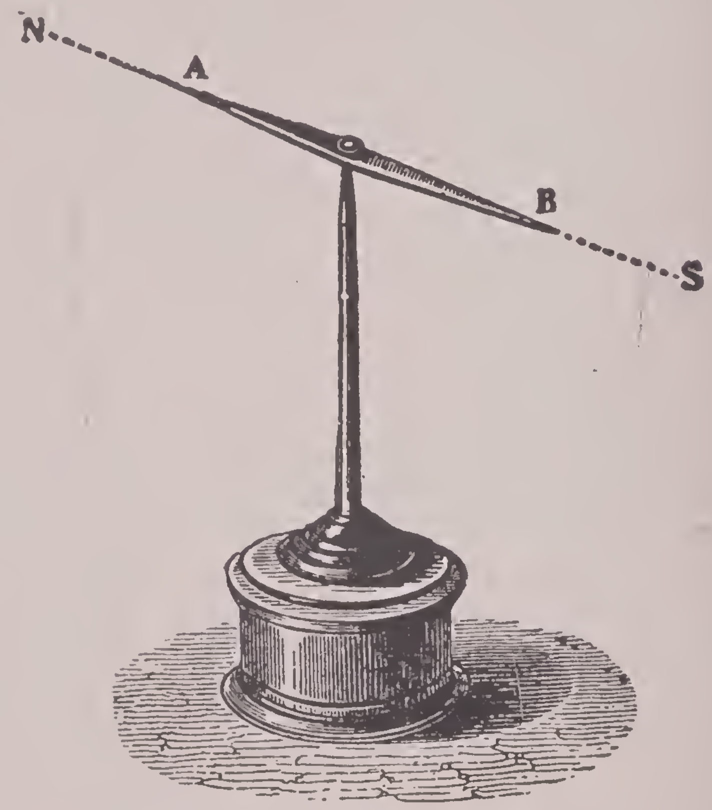

Fig. 69. Magnetic Needle.

1. Bend a stirrup of copper or brass wire and suspend the bar in it. Hang the whole by a single thread that has been untwisted and soaked in water long enough to take out all the twist. If the bar persistently returns to the north and south line after being moved out of it; then it is a magnet.

2. As a further precaution procure a magnet needle from some dealer and suspend it as in Test 1. If it satisfies this test proceed to take your bar in hand and cautiously approach one end of the magnet. Should it at-

tract it reverse the piece in your hand, and it should now repel. If it does all right, it is a magnet; if it does not, it is not a magnet.

Question 10. Why is the repulsion test more important than the attraction?

Answer. Because any piece of iron or steel will be attracted to a magnet but only a magnet will ever be repelled.

Question 11. Is this rule absolute?

Answer. Hitherto only iron, steel and nickel have been mentioned as capable of being made magnets. Cobalt and manganese possess, limitedly, the same capability. Metals of this character are called Paramagnetic, and are attracted by the poles of magnets. There are other substances, among which are phosphorous, bismuth, zinc and antimony, which act in a contrary manner, being repulsed by magnets. These substances are known as Diamagnetic substances.

This repulsion is so weak that it can never be mistaken for the repulsion of a magnet by a magnet. Furthermore, these diamagnetic metals are repelled by either end of a magnet.

Question 12. What are the poles of a magnet?

Answer. The ends of a magnet are called its poles.

Question 13. How are the poles named?

Answer. The end which points to the north geographical pole is called the north pole of the magnet, the other end is called the south pole of the magnet.

Question 14. How are the poles marked?

Answer. The north pole with an N or a line cut in the steel, the other end is left unmarked.

Question 15. What is the polarity of a magnet?

Answer. By polarity we mean the nature of the magnetism at a particular point, whether it is north or south magnetism.

Question 16. What are consequent poles?

Answer. In long magnets extra poles may be found besides the poles at the ends. These extra poles always come in pairs. Such a magnet is shown in Fig. 70.

Question 17. What rule gives the results of magnetic attraction and repulsion?

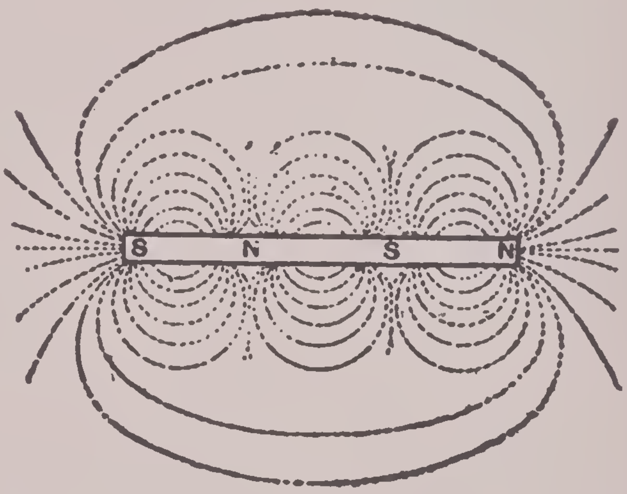

Fig. 70. A Magnet with Consequent Poles.

Answer. Either pole of a magnet attracts a magnetizable metal. Like poles repel, unlike poles attract.

If you take a magnet a foot long and brutally jab it at a tiny compass needle this rule may not work and the reason is this: The great power of the large magnet sweeps out the private magnetism of the compass and replaces it by magnetism whose poles are just the opposite to that which was formerly there. When the poles are reversed, then where there was repulsion there will now be attraction.

Question 18. But the end of the magnet which points to the north geographical pole is called the north pole of the magnet?

Answer. Yes, for convenience we do say this and then to get out of the difficulty we say that the south magnetic pole of the earth is up at the north geographic pole.

It must be definitely understood that when we speak of the "magnetic north pole" we mean that spot on the earth's surface which exhibits "south polarity."

When we speak of the north pole of a magnet we can avoid any confusion by saying the "north seeking pole."

Question 19. Has the earth polarity?

Answer. Yes, the region around the north geographic pole has south pole magnetic polarity. Around the south geographic pole there is north pole magnetic polarity.

Question 20. Is not the north magnetic pole exactly at the north geographic pole?

Answer. No. Standing in Chicago the compass points a little east of the geographic north. At San Francisco it points 16 degrees* east and in New York 10 degrees west of the true north.

Question 21. Why is this?

Answer. The magnetic north pole is about 1400 miles south of the north pole and looking from New York about 10 degrees west of it. Why the magnetic pole should be here instead of at the north pole we do not know.

Question 22. Are there any places where the compass points to the north pole?

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*If the circumference of any circle is divided into 360 equal portions, each is called a degree. A right angle embraces 90° (° is abbreviation for degree).

All degrees are not of the same size unless the circles happen to be the same size.

Answer. Yes. There is a ring around the earth where the compass points north. This ring is an irregular line. In the United States, Charleston, S. C., the east end of Tennessee, Columbus, Ohio, and Lansing, Mich., are on this *Agonic* line. It crosses Russia, Persia and Australia.

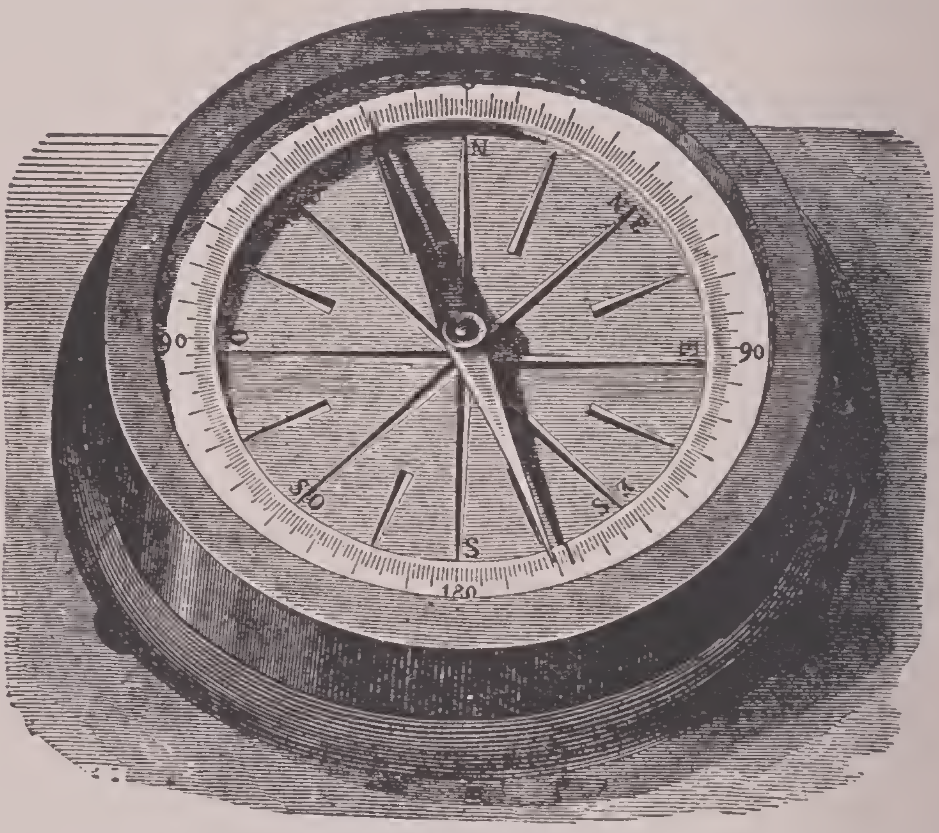


Fig. 71. A Compass marked with Degrees as well as the Points of the Compass.

Question 23. Is the magnetic north pole fixed?

Answer. No. In 1580 in London the needle pointed 11° east of north, it gradually swung over till in 1657 it pointed true north, it kept on till in 1816 it pointed 24° west of north and then it swung back so that in 1907 it points about 15° west of north. It seems as if it took about 320 years to make a complete swing.

Question 24. What name is given to this peculiarity of the compass?

Answer. It is called the *Declination* of the compass. It may be easily remembered because the compass declines to point true north.

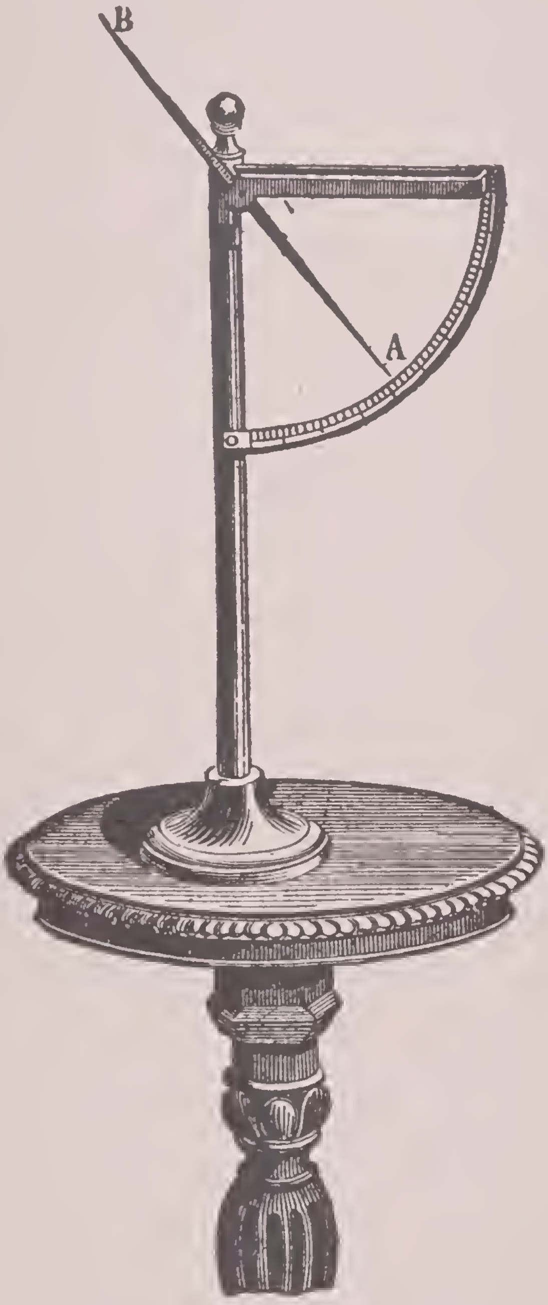


Fig. 72. Dipping Needle.

Question 25. What is a compass?

Answer. The usual compass is a magnetic needle suspended over a card bearing the names of the points of the compass and sometimes the 360° of the circle are marked out. Fig. 71.

Question 26. Why do home made compasses balance badly? One end seems too heavy.

Answer. Near the equator of the earth a needle may be balanced and then magnetized, but in other places if the needle is balanced and then magnetized one end of the needle will dip. Fig. 69 shows this. If the needle is mounted so that it can turn with perfect freedom vertically as in Fig. 72 it will in Chicago incline from the horizontal line about 70°.

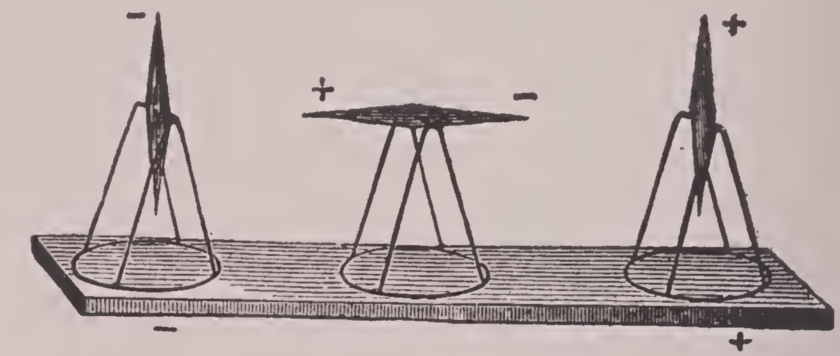


Fig. 73. **Showing Dip or Inclination of Needle at Magnetic north pole, Magnetic equator, Magnetic south pole.**

Question 27. Is this Inclination of the needle the same all over the world?

Answer. No. In Fig. 73 is shown the *Dip* or Inclination of the needle at the magnetic north pole, magnetic equator and magnetic south pole. As you leave the equator going either way the dip increases until you reach the poles.

Question 28. How is the dip neutralized in compasses

Answer. By balancing the needle after magnetizing, or if the compass must be used all over the world by attaching a tiny sliding weight.

North of magnetic equator the weight is put on south end of needle and south of it it is put on the north end of needle.

Question 29. What is the magnetic equator?

Answer. It is an irregular line running around the world, being north of the geographic equator on Atlantic ocean and south of it on Pacific ocean. Along this line there is no dip to the needle.

Question 30. Do you consider the earth a huge spherical magnet?

Answer. Yes. These experiments tend to show that the earth is a magnet, for it magnetizes objects.

Experiment 1. Procure a small pocket compass, and hold this so that the needle will move freely, against an iron stovepipe. Raise and lower it past the joints in the pipe, and as a rule the action of the needle will show that there is a change of polarity at each joint, the ends of the needle being alternately attracted in passing.

Experiment 2. With the same compass explore the polarity of any permanent piece of iron, such as a balcony, an iron safe, a gas or water pipe which lies in a north and south position, and it will generally be found that the north and south extremities between joints will show different polarities.

Experiment 3. Explore the polarity of a street car rail lying in a north and south street. Its polarity will be found to be lengthwise of the rail. Now try a rail lying in an east and west position, and it will generally show a polarity at right angles to the length of the rail—the north side will show one polarity, while the south will show the other.

Experiment 4. Take a fine cambric needle from a package which has been lying in a north and south position, and drop it carefully on a glass of water. In the majority of cases, if properly handled, it will float, and generally show polarity by settling in a north and south position.

Experiment 5. If now, while this needle is lying on the surface of the water we approach it carefully with the compass, one pole will be attracted, and the other pole will be repelled. That is, the two ends of the compass needle will repel the like ends of the floating needle, but will attract the dissimilar ends. This experiment may be made still easier by floating the needle with a tiny bit of cork through which it has been thrust.

Question 31. Can the earth's magnetism be shown in any other way?

Answer. Yes, if a bar of hard steel or even hard iron and some iron filings are procured.

Hold the bar level in an east and west position and strike one end a smart blow with a hammer. Now dip it in the iron filings and we shall find it has little or no magnetism, at least in its length. Now point it downward at an angle corresponding to the latitude where you are, so as to point to the actual north magnetic pole as nearly as possible, and strike the end of the bar, as before. You will find that the bar has acquired a quite perceptible amount of magnetism; that either end will attract the iron filings, tacks or other bits of iron, and that the phenomena of attraction and repulsion will be shown by bringing it near the compass needle.

Now, having marked the end which attracts the south end of the needle with paint or chalk as the N pole, we again point it to the north pole of the earth, but in a reversed position, and strike it again as before. On testing for magnetism we will find that the particles of iron adhere as before, but what we marked as the N pole of our magnet has become the S pole, and repels the end of the needle it attracted before.

LESSON 11.

MAGNETISM—CONTINUED.

Question 1. For the experiment in A. 31 of Lesson 10 why is it necessary to take hard steel to get best results?

Answer. We know that wrought iron becomes a magnet readily, steel castings are easily magnetized, cast iron less easily and hard steel is the most difficult of all to magnetize. The more difficult it is to magnetize a substance, the better it retains its magnetism. If you want a permanent magnet use hard steel. If you want a temporary magnet use iron or steel castings.

Question 2. Do you mean steel castings or cast steel?

Answer. I mean steel castings which are made of Bessemer steel. Cast steel is a high grade steel which is expensive and is used for tools, etc.

Question 3. Does magnetism permeate some metals better than others?

Answer. Yes. We say that some metals have greater permeability than others.

Wrought iron is the most permeable, cast iron the least permeable, of the cheaper metals. Hard steel has small permeability.

Question 4. Do some metals retain magnetism better than others?

Answer. Yes. The retentivity of wrought iron is least, and that of cast iron the greatest of the commonly used metals. Hard steel has great retentivity.

Question 5. How can you explain the facts of different permeability and retentivity?

Answer. We know the following facts, and from these we have thought out an explanation which we think is correct.

Facts:—

(1) The softest iron is the most permeable.

(2) Soft grey cast iron has greater permeability than hard white cast iron.

(3) The harder the steel the less permeability.

(4) When a bar of iron or steel is suddenly magnetized there is a faint click and the bar lengthens slightly. If magnetized and demagnetized rapidly the clicks will merge into a hum or buzz. Keeping this up for a length of time heats the bar.

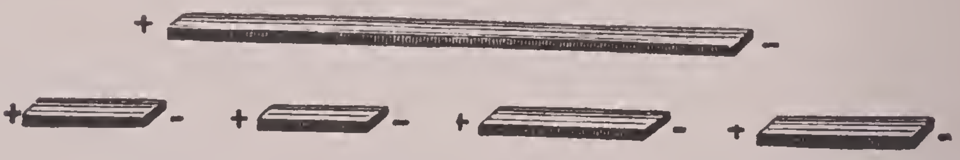


Fig. 74. The result of Breaking a Magnet is Several Short Magnets.

(5) Pounding or jarring a permanent magnet weakens it. So does heating it red hot.

(6) If a magnet is broken, each piece is a perfect magnet with two poles. No matter into how many pieces you break a magnet, each is still a magnet. See Fig. 74.

(7) If a thick piece of steel is magnetized and then laid in nitric acid for some time, when the outer surface has been eaten off, a test for magnetism will show that the bar has lost almost all its polarity. Magnetism is evidently only skin deep.

(8) Four bars 6 x 1 x ¼ inches magnetized and

bound together make a much stronger magnet than one bar 6 x 1 x 1 magnetized from as powerful a source.

Theory:—

From the above facts we have concluded that a piece of iron or steel is not solid but comprised of innumerable small particles which are each a perfect magnet.

In ordinary iron or steel these are all jumbled up as in Fig. 75, and do not show any magnetism.

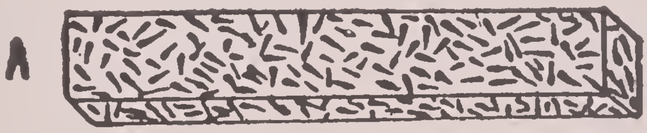


Fig. 75. A Bar of Iron Unmagnetized.

There being about as many north and south poles pointing the same way, they neutralize each other.

Now suppose this bar be stroked by a magnet as in Fig. 65. The influence of the magnet will be strongest at the surface and weaker as it penetrates. In fact, after ⅛-inch under surface the action is practically nothing.

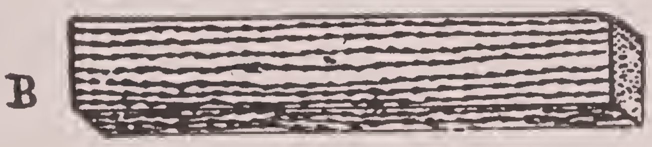


Fig. 76. A Bar of Iron while magnetized.

What this magnet does is to pull all the little particles around into line with the north poles pointing one way and the south poles the other. This movement of the particles causes a slight noise if they move all at once, but the gradual movement due to the stroking does not produce a sound that we can hear. If the rod is iron it lengthens a tiny bit; if it is a nickel rod it shortens a little (about 1-700000 of its own length).

The rapid magnetizing and demagnetizing pulls them around so fast that the internal friction heats the bar.

Fig. 76 shows the bar with the particles all in line, and as each particle is a miniature magnet, Fig. 77 shows why the whole bar becomes a magnet.

If now the magnet be pounded the vibrations shake up the particles and they get jumbled up and the bar ceases to show its magnetism.

The harder the iron or steel the more difficult it becomes to pull the particles into line and make a magnet. In the same way once magnetized the better they stay in position.

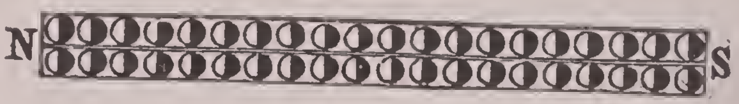


Fig. 77. Internal Structure of a magnetized Bar.

Very soft wrought iron may be magnetized easily, but as soon as the magnetizing force is removed the particles slip back to the jumbled condition.

A glass tube filled with cast iron filings may be magnetized by a coil of wire. On examination the filings will be seen all arranged, end for end.

Handled carefully it will act as a magnet, but when shaken so as to jumble up the filings it loses its polarity.

You notice we do not say it loses its magnetism, for it does not. It ceases to have magnetic poles at each end, i. e., it has lost its polarity.

When we say demagnetize a bar, it would be more accurate to say depolarize.

We use this word, however, for a different thing and say demagnetize, for every one understands what we mean.

Question 6. Will a magnet floated on water by corks be drawn to north or south?

Answer. No. The force that the earth exerts on a magnet will only turn it into the north and south line.

The poles of the earth are so far away and the magnet so small that the distance between the two poles of the magnet is practically nothing as compared with the distance from magnet to either pole.

The south magnetic pole of the earth attracts one end and repels the other end of the magnet. The forces are equal because distances are equal. The same thing happens at other end of the magnet. The result is no motion.

Question 7. Can the earth's tendency to turn a compass needle be neutralized?

Answer. Yes. Take a bar magnet and hold it high above and parallel with the compass needle. Let its north pole point in the same direction as the north pole of the compass needle.

Slowly lower the magnet until the compass needle starts to waver. If the magnet is fastened in this position the compass needle will stay in any position it is placed.

Question 8. Is this of any practical use?

Answer. Yes. If surrounding iron objects or magnetized things are interfering with the earth's effect on the compass, then by means of extra magnets these disturbing influences may be neutralized and the earth's magnetism alone left free to turn the compass.

This must be done with compasses on iron or steel ships.

Question 9. What is meant by magnetic force?

Answer. The force exerted by one magnet on another to attract it or to repel it, or to attract iron filings or pieces of iron is termed magnetic force.

Question 10. Does this force act all over the magnet?

Answer. There is almost none in the center, and most at the ends. Plunging the end of a magnet into a box of iron filings shows this.

Question 11. What are the relative magnetic forces at different points from the center to the end of a magnet?

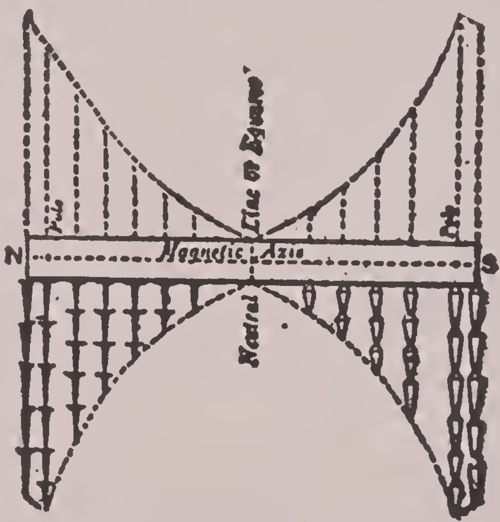


Fig. 78. Strength of Magnetism as roughly Tested by Lifting Power.

Answer. Fig. 78 shows approximately the magnetic force at different points. It shows that the pole of a magnet is not at the tip end, but a little way back.

An accurate test of a six-inch bar magnet has shown these results:

Location of Point.	Magnetic Strength.	
Center	None	
½″ away	9 units	
1	20	
1½	33	Other end gave same results
2	48	
2½	65	
2¾ Pole	84	
3 Tip end	80	

Question 12. What are the magnetic lines of force?

Answer. These words are used in several different ways. The word magnetic is usually dropped for the sake of shortness and "lines of force" spoken about. Engineers usually say "lines."

(1) The magnetic force of a magnet seems to lie along certain lines and these lines are called "lines of force." Perhaps "direction of force" would be a better name.

(2) When a magnetic pole exerts a certain force of repulsion on the same named pole of a magnet of equal strength we say that there are 10,000 "lines of force" to the square inch in that magnet pole. If it exerted twice that force we would say there were 20,000 lines to the square inch.

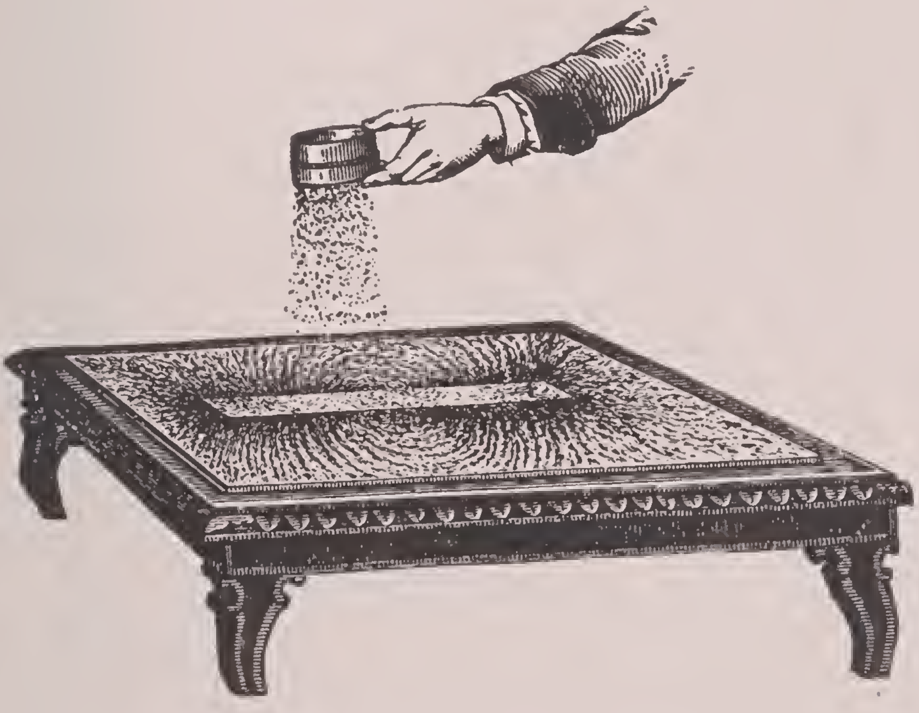


Fig. 79. Lines of Magnetic Action around a Bar Magnet.

Perhaps "units of force" would be a better name for this.

It has been proposed to drop the expression "line of force" when used as "units of force," and say 10,000 gausses. Whether this word will be adopted or not remains to be seen.

Question 13. How may the direction of force be ascertained?

Answer. Place the bar magnet on a table (Fig. 79) and lay over it a sheet of glass.

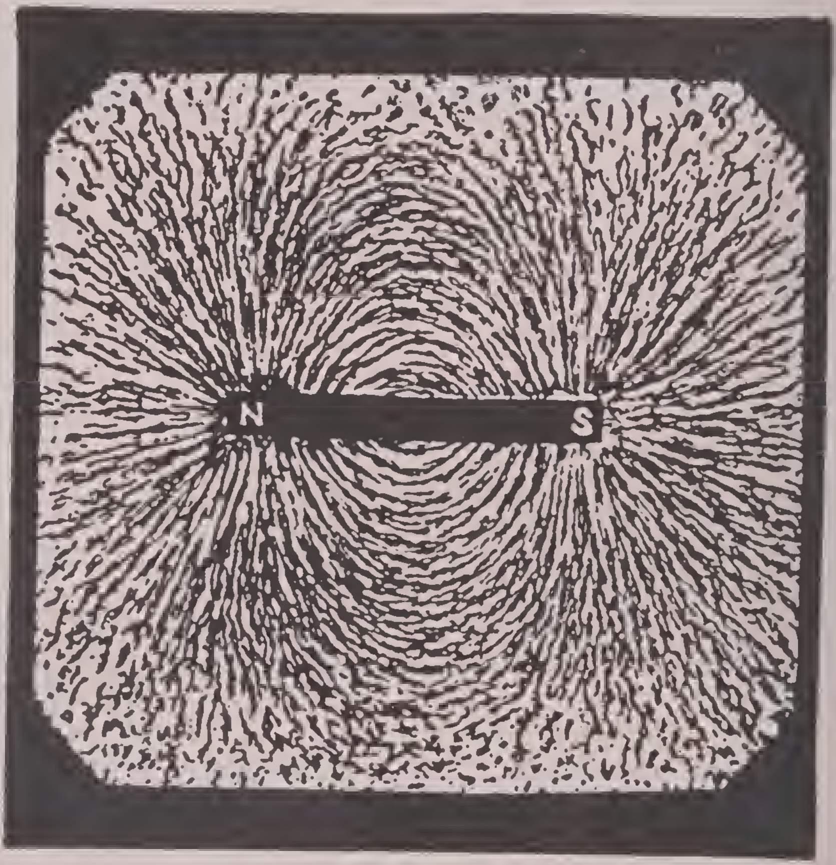


Fig. 80. The Magnetic Field of a Bar Magnet as shown by Iron Filings.

Lift iron filings over the glass and tap very gently. The filings will arrange themselves and show the direction of the magnetic force at all points.

Many different combinations of poles should be tried. Figs. 80 and 81 show two magnetic spectrums.

Question 14. What is a magnetic field?

Answer. The space around a magnet under its influence is called a magnetic field.

The spectrum made with iron filings shows the directions of the magnetic forces in the magnetic field.

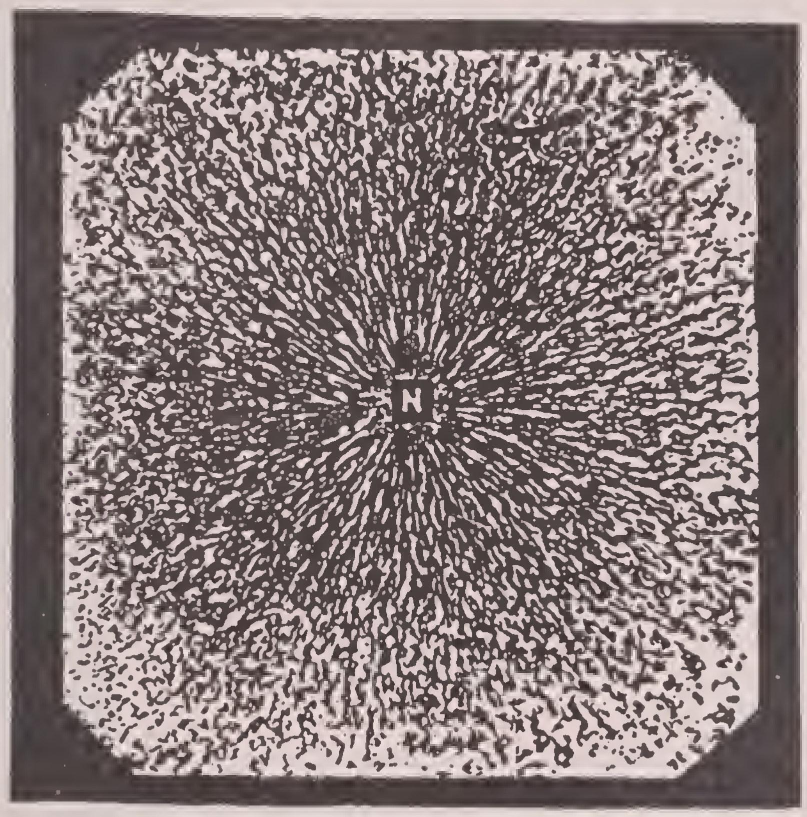


Fig. 81. The Magnetic Field of a Magnet Pole. Magnet at Right Angles to Observer.

Question 15. What is magnetic induction?

Answer. When a piece of soft iron free from magnetism is placed in a magnetic field it becomes a magnet by induction.

Fig. 82 shows this. The part of the iron under the north pole of the magnet becomes a south pole.

It may be difficult to find a piece of iron which is not slightly magnetized.

Question 16. How can you demagnetize?

Answer. Heat to a cherry red and cool very slowly. The piece may be now hardened and tempered and no magnetism will appear.

Question 17. Explain magnetic induction more fully

Answer. (1) Hold a magnet horizontally and attach to its north pole a soft iron nail. To this nail attach another until three or four are adhering to the magnet. The end of the first nail which is in contact with the north pole of the magnet becomes a south pole by induction. This temporary polarity of the first nail acts on the other, and so on down the line of nails. The polarity of the nails is shown by small letters on the left side of the nails in Fig. 83.

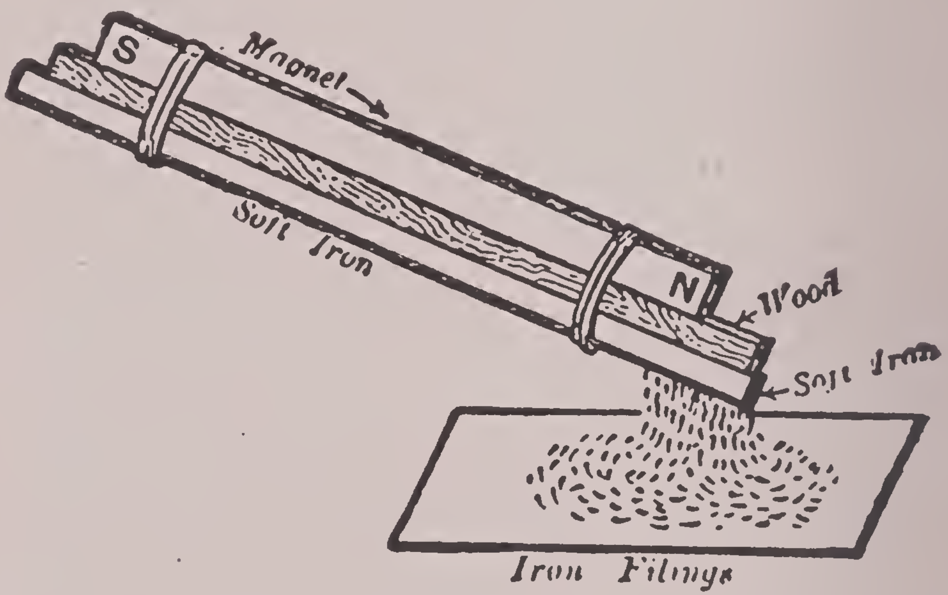


Fig. 82. The Induction of Magnetism in Iron without Contact.

Now slide the south pole of a similar magnet (the other one of the pair) over the north of the first magnet.

This magnet will act inductively on the nails, and the small letters on the right side of the nails show the polarities induced.

The result of the two effects is to render the nails neutral, and they drop off.

(2) Attach nail to one magnet as before and then as in Fig. 84 place the other magnet below. The effect of the upper magnet is the same as before. The lower magnet acts inductively on the nails, but the south pole of the magnet acts on the lower end of the last nail, so that the polarities induced are the same as those induced by the upper magnet. The result is a stronger magnetic action than before. It will be seen by experiment that more nails can be supported.

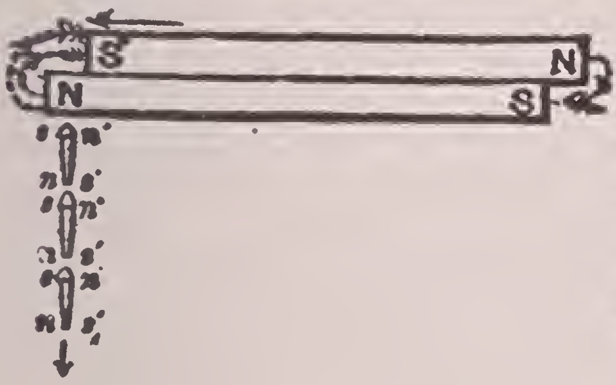


Fig. 83. Demagnetizing Inductive Effect of Unlike Poles.

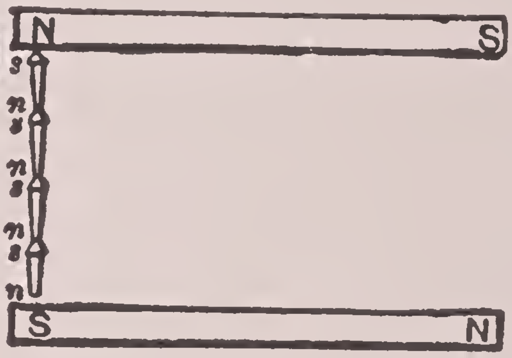


Fig. 84. Increased Magnetizing Effect of Unlike Poles.

Only one set of small letters is used because both magnets induce the same polarities.

(3) If, as in Fig. 85, the two magnets are held together, we have the same effect as if a stronger magnet were used.

(4) Placing the second magnet below as in Fig. 86 results in demagnetizing the nails. The left-hand letters show effect of upper magnet, the right-hand letters

the effect of the lower magnet. Net effect, no magnetism.

A slightly different explanation of these four facts will be given in Lesson 13. This explanation will be no better, but merely telling the same thing in a different way.

Question 18. Is there any material which will insulate from magnetism?

Answer. No. Deflect a compass needle slightly by a bar magnet. Slip in between them thick sheets of cardboard, copper, wood, glass, rubber, in fact anything but iron or steel, or perhaps a thick slab of nickel, and the deflection of the needle is not affected.

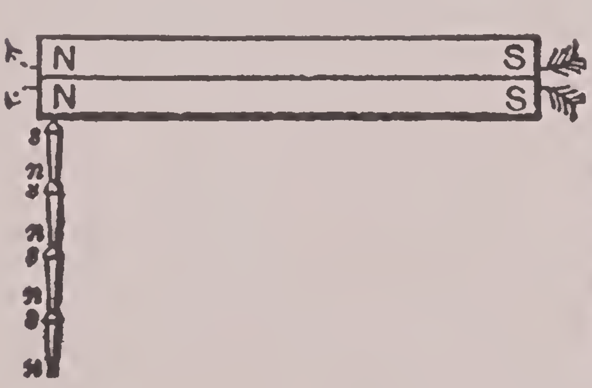


Fig. 85. Increased Magnetizing Effect of Like Poles.

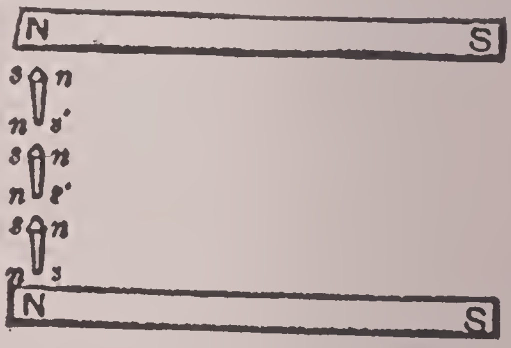


Fig. 86. Demagnetizing Inductive Effect of Like Poles.

This shows that magnetism passes through anything.

Question 19. What would be the result if a piece of iron or steel were placed between needle and magnet?

Answer. If a sheet of steel, iron (wrought or cast), is interposed the deflection will become much less.

Question 20. How do you explain this?

Answer. It seems that everything conducts magnetism equally well, but perhaps equally poorly would be more accurate, except iron or steel. Therefore the magnet does not care or even know that something else has been put in place of part of the air through which it must send its force or effect. But when the iron is put in place it is so much better a conductor that the magnetic effect prefers the easy path through the iron off to the side, instead of going on into the air beyond. Hence only a little effect passes on to the compass. Indeed, if the iron screen were thick enough in proportion to the strength of the magnetism present, none would pass through.

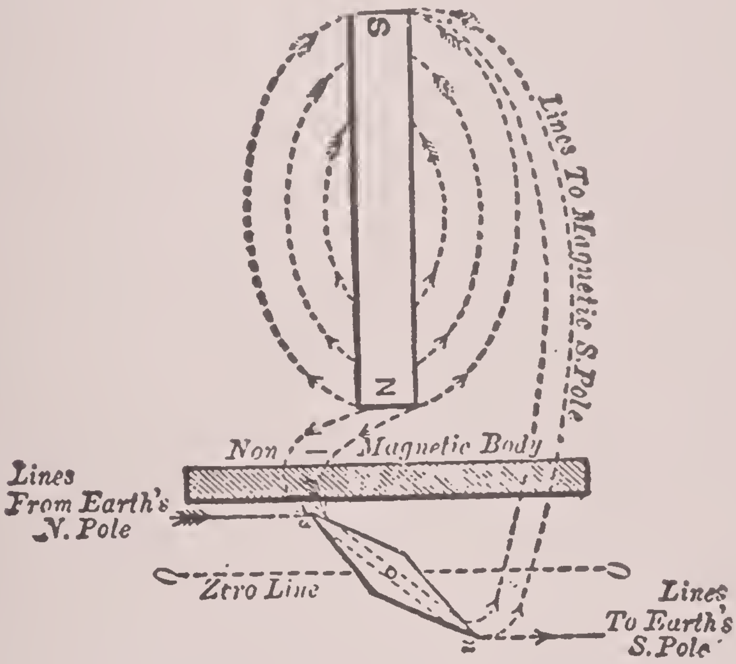


Fig. 87. Needle Deflected Through a Non-Magnetic Body.

These effects are shown in Figs. 87 and 88. The lines along which the magnetic force acts are also shown.

Question 21. Are there any practical uses of the screening action?

Answer. Yes, several uses are made of it.

(1) Advantage is taken of this fact by putting an extra hunting case of soft iron on a watch to screen it from the magnetism of electrical machinery.

(2) Measuring instruments used on switchboards or near dynamos are enclosed in heavy cast-iron cases.

(3) Galvanometers are sometimes surrounded by a cylinder of wrought iron, or a piece of heavy iron pipe. A small hole is cut in the side, so as to observe the deflection of the needle.

Question 22. To what practical use are permanent magnets put?

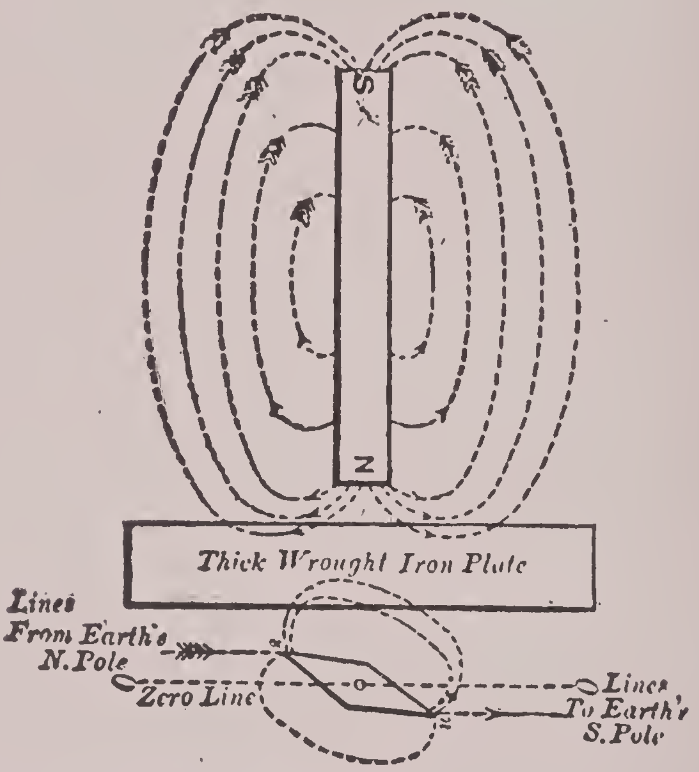


Fig. 88. Needle Screened from Action of a Magnet by a Magnetic Body.

Answer. They are used in the receivers of telephones; in magneto bells for telephone calling and general signalling; in the magnetos used for ignition purposes in gas, gasolene and oil engines; as magnets in measuring instruments.

Question 23. How are magnets named?

Answer. When an engineer or electrician speaks of a magnet he means an electro-magnet; when he says permanent magnet he means a piece of hard steel which has been magnetized. In referring to a piece of iron temporarily magnetized he calls it an armature or a core.

LESSON 12.

ELECTRO-MAGNETISM.

It is well known that all the effects due to a natural magnet or an artificial magnet, can be produced by a current of electricity.

The effects produced by the electric current are so much more powerful than natural magnetism, and the cost is so much less that they are almost universally used.

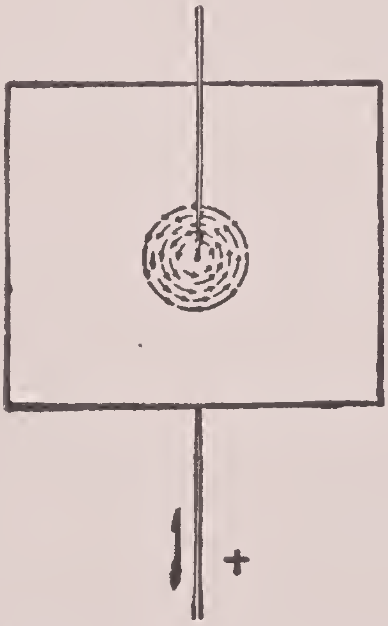


Fig. 89. Magnetic Field due to Electric Current.

Question 1. What is electro-magnetism?

Answer. It is the magnetic effect produced by a flow of electric current.

Question 2. Does a wire carrying current have a magnetic field?

Answer. Yes. Pass a straight wire carrying a large current through the center of a sheet of cardboard as shown in Fig. 89. If iron filings are sprinkled on the board they will arrange themselves in circles around the wire, thus showing the magnetic field.

Question 3. Will the wire affect a magnetic needle?

Answer. Yes. If a small compass be placed on the cardboard and pushed around the wire it will be seen that the needle is being moved by the magnetic action of the current in the wire.

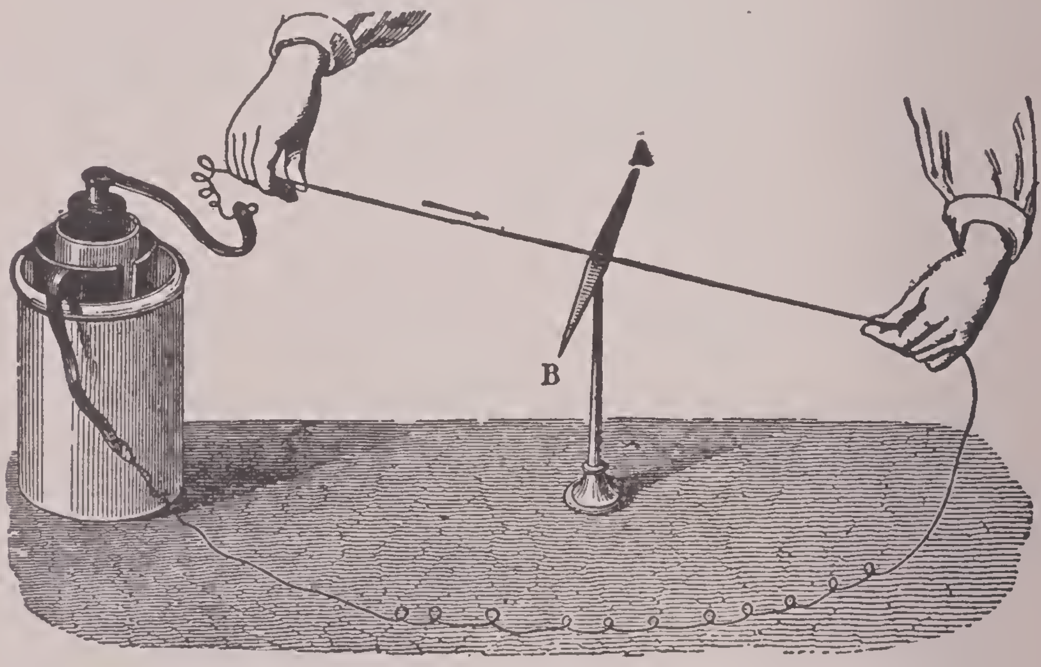


Fig. 90. Action of Electric Current on Magnetic Needle.

It is also easily shown by holding a wire carrying current over a magnetic needle. The needle will be turned and stand at an angle to the wire. Fig. 90 shows this.

Question 4. Does the wire exhibit north and south polarity like a bar magnet?

Answer. No, not like a bar magnet. It moves the magnetic needle in the following way: When the current flows from the South to North Over the needle the N-end turns West.

This is called the SNOW rule, so called from the first letters of the important words of the rule.

To test this rule arrange things as in Fig. 91. Turn the cell so that a line through the copper and zinc plates will be north and south, and have the copper plate to the south. Bend your wire circuit into a loop standing vertically in the N. and S. line. Stand behind the zinc plate facing south; put a small compass in this loop with the N. mark on the box pointing to the north.

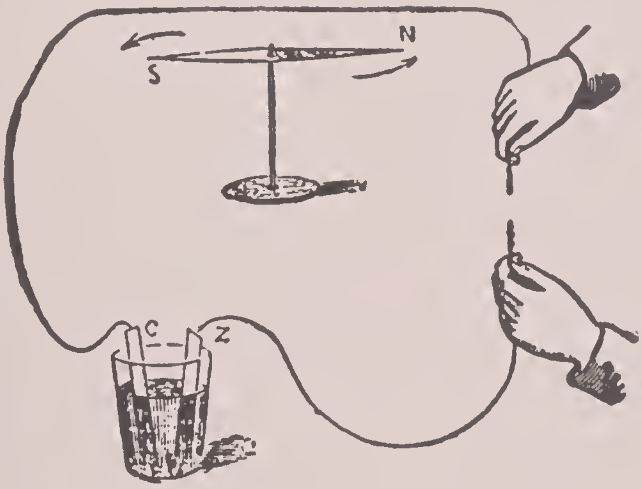


Fig. 91. The S-N-O-W Rule.

If the circuit is *open,* i. e. the dry ends of the plates not touching, and the connecting wires cut and the ends held apart, then the N-end of the needle will as usual point to the north.

Close the circuit by touching the ends of the wire, and the N-end of the compass will move to the west (to your right hand). Since we say the current flows from carbon to zinc plates, this proves our rule correct.

Question. 5. Give a further proof that although the current acts magnetically it does not act like a bar magnet.

Answer. If the wire were a simple bar magnet putting the current under the needle would not change the direction of the deflection, but it does change the direction of the deflection. Further if the wire were like a bar magnet when the current was reversed it would change in polarity and attract the needle holding it in the north and south line, but it does not do this. When the current is reversed it deflects the needle the other way.

Question 6. Why does the current act in this way on a magnetic needle?

Answer. We do not know. The current acts as if it had a paddle wheel of magnetism rotating on the wire as an axle and in the opposite direction to the hands of a watch when the current is flowing towards you.

Standing in the position shown in Fig. 91, when the current is over the needle flowing towards us (north), the part of the *whirls* (paddle wheels) of magnetism on the under side of the wire are turning towards the west and knock the N-end of the needle in that direction, and since the S-end always does the opposite thing it goes east.

But moving the wire under the needle the parts of the whirls on top of the wire are moving east and push the N-end of the needle in that direction.

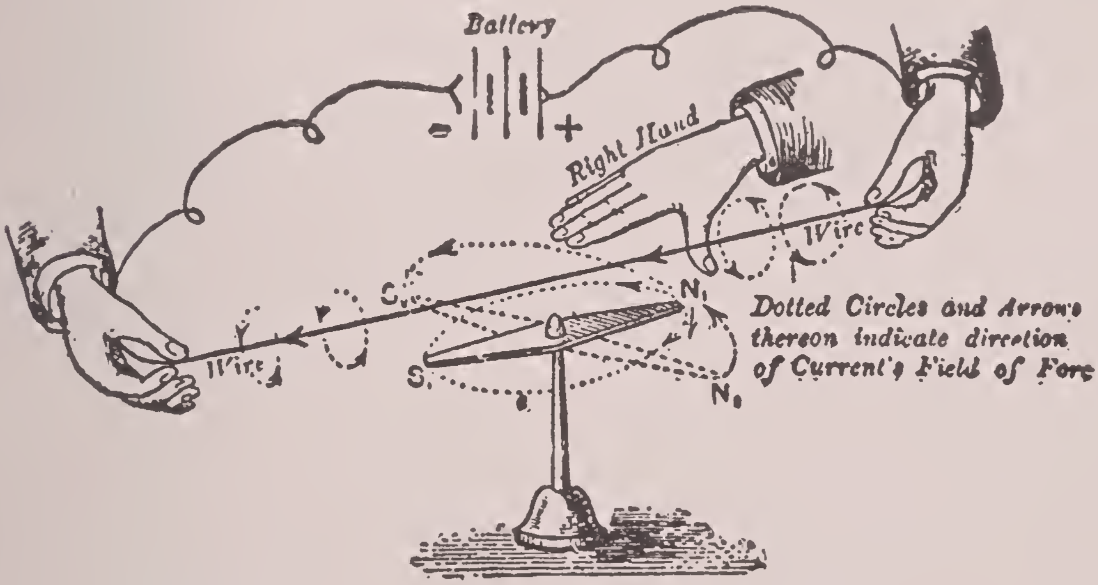
Fig. 92 shows the magnetic whirls around the wire, and the effect of the SNOW rule. For since the current runs in the opposite direction from the rule, we should expect to find the N-end of the needle move in the opposite direction. This is exactly what it does. The N-end of the needle moves East.

This may be made into a rule and called the NOSE rule.

When a current flows from North Over a needle to the South the N-end is deflected East.

Question 7. For what is the extra hand in Fig. 92?

Answer. The extra right hand shown in the illustration is another way of remembering the SNOW rule, and is especially adapted to discover in which direction the current flows.



Dotted Circles and Arrows thereon indicate direction of Current's Field of Forc

Fig. 92. Action of Current on a Magnet.

Arrange the wire ABOVE *the needle in a N and S line placing the palm of* RIGHT HAND OVER *the wire with the* THUMB *stretched out at right angles to the hand and pointing towards the* N-END *of the needle. The* FINGERS *point* IN THE DIRECTION *the current flows.*

Question 8. What is an electro-magnet?

Answer. An electro-magnet consists of a coil of wire, a piece of soft iron to fill the hollow of the coil and a current to pass through the wire.

Fig. 93 shows this, as well as the lines of magnetic action.

Question 9. What are the technical names of the parts of an electro-magnet?

Answer (1) The iron is called the core.

(2) The coil of wire is called a helix.

(3) The helix carrying current (without a core) is called a solenoid.

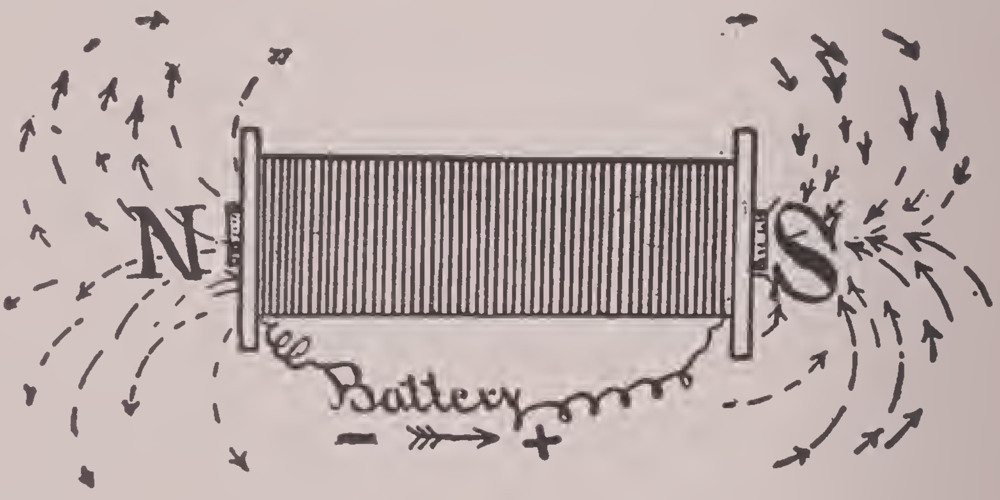


Fig. 93. An Electro-Magnet with its Magnetic Field.

(4) A core placed in a solenoid makes it an electro-magnet.

Remember plugs of brass, fiber or other materials placed in a solenoid are not cores in the technical sense of the word.

(5) The helix or coil is usually not wound on the core but on a spool of brass or bronze. The ends of this spool are called the flanges and show in Fig. 93.

(6) On horse shoe magnets the iron connecting the two cores is called the yoke.

Question 10. Why is the left end an N-pole and the right end a S-pole. (In Fig. 93).

Answer. The polarity of a magnet depends on the direction of the current flow through the helix.

In Figs. 94 and 95 the current enters at the right hand end of the helix, but being wound, one right handed and the other left handed the polarities developed are as shown.

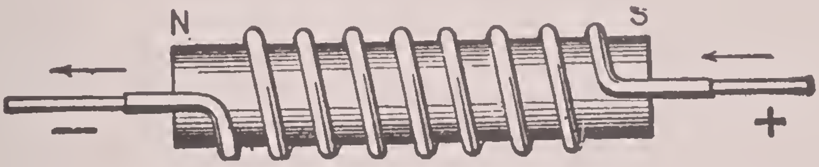


Fig. 94. Electro-Magnet with Right-handed Helix.

Question 11. What rule will give you the polarity of a magnet?

Answer. Hold the magnet so that the current flows through the helix away from you. If the current flows round the core in the direction that the hands of a watch or clock move, the pole you are looking at is an S-pole. If the current went counter-clock wise around the core, the pole is an N-pole.

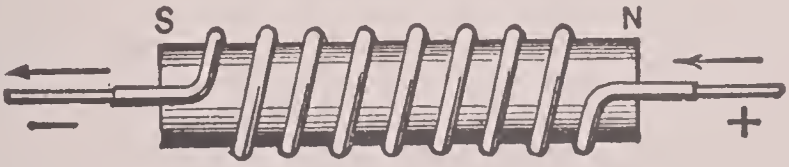


Fig. 95. Electro-Magnet with Left-handed Helix.

Question 12. Is there any other rule?

Answer. Yes. It is a rule especially applicable to winding horse shoe magnets so that both legs of the magnet will not be accidentally made of the same polarity.

Write on the pole piece the letter S or N as the case may be and put arrow heads on the ends of the letters as in Fig. 96. These arrow heads show the direction the current must flow around the core to give the polarity indicated by the letter.

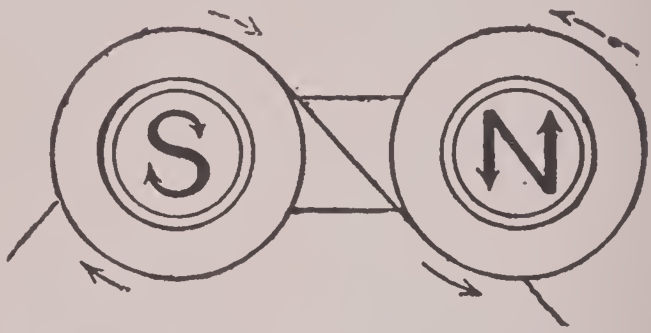


Fig. 96. Rule for Proper Winding of Horse-shoe Magnets.

Question 13. What is the strength of a magnet?

Answer. The term "the strength of a magnet" is used very carelessly. Some people mean its lifting power, while engineers and electricians mean the actual quantity of magnetism flowing from a pole piece.* The expression "strength of a magnet" should only be used as engineers or electricians use it.

Question 14. What is the lifting power of a magnet?

Answer. It is the number of pounds the magnet will hold up, when things are arranged as in Figs. 97 and 98.

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*In electro-magnets when we say pole we generally mean the end of the core. Usually we say pole piece, meaning the surface at the end of the core, or the piece of iron which is screwed, bolted or even cast on the core to make the actual pole larger than the core.

There are some very curious things about lifting power. It depends upon the shape of the magnet, and the actual quantity of magnetism. A horse shoe magnet will lift three or four times as much as a bar magnet of equal strength. A long bar magnet will lift more than a short one; the actual quantity of magnetism being the same.

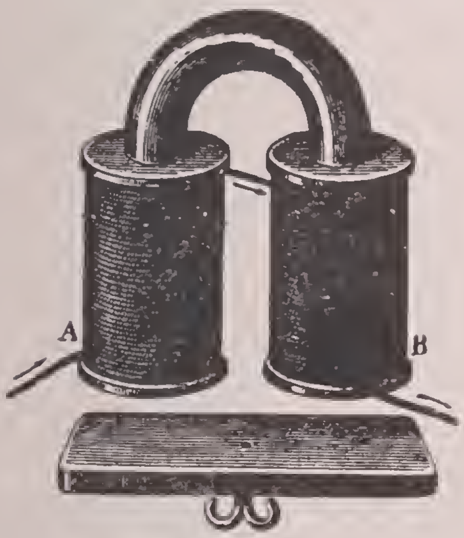

Fig. 97. Horse-shoe Magnet Arranged for Test of Lifting Power.

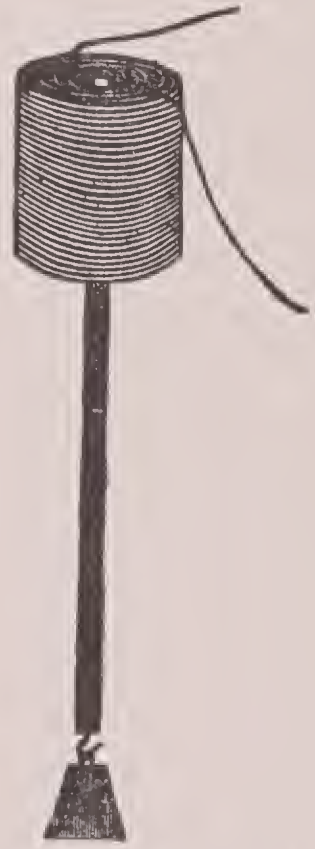

Fig. 98. Testing Lifting Power of a Solenoid.

A magnet with round or pointed pole pieces will lift more than the same magnet with flat or broadened pole pieces. The same magnet may have its lifting power changed by unscrewing its pole pieces and screwing on a flatter set.

It is an excellent joke to wind a horse shoe magnet with one pole piece flat and the other rounded. If one will hold 5 pounds the rounded one will hold 6 pounds.

A magnet having its armature loaded almost to the pulling off point, may have its load increased slightly the next day. This gradual increase of the load may be attempted every day until finally the armature will be torn off.

It will be found that the last day the magnet was holding up a load that it could not have held had it been applied all at once. This may be easily proved by trying a load a little less than that which tore the armature away. The magnet will not be able to hold it.

Doubling the strength of the same magnet more than doubles its lifting power, but a magnet will not pull twice as strongly if you move up twice as close to it.

A test made with the armature in contact with the poles of the magnet with increases in the magnets' strength gives practically the following results for lifting power.

Do not forget that doubling the current in an electro magnets coil does not double the strength. This will be fully explained later.

Test 1.

Relative strength of Magnet.	Relative lifting power.
1	1
2	4
3	9
4	16
5	25
6	36
7	49
8	64
9	81
10	100

Test 2.

A test made with a horse shoe magnet to determine its lifting power at different distances from its poles shows the following results:

Distance away from poles.	Lifting power.
0	82.0
1	35.0
2	25.0
3	20.0
4	15.1
5	12.1
6	11.3
7	9.3
8	7.4
9	6.5
10	5.5

LAW OF DIRECT AND INVERSE SQUARES.

The results of Test 1 are not the actual figures in the test. They have been increased or diminished a little in order to illustrate what is called the *Law of Direct Squares.*

By looking at the table of results you will notice that the lifting power is always the strength of the magnet multiplied by itself. For instance when the magnet was 5 times as strong as before it lifted 5x5 or 25 times as much.

When the magnet strength was increased from 1 to 2 the lifting power was increased from 1 to 4. Doubling the strength quadrupled (2x2) the lifting power.

With a magnet 5 units strength, doubling its strength, quadrupled its lifting power; increased it from 25 to 100.

We call a number multiplied by itself a square. The number which is multiplied we call the *square root.*

To find the lifting power of a magnet square its strength.

Having found this rule we could go farther than the results of the test and predict that if the magnet had been increased in strength to 12 times the original value, the lifting power would be 12x12 or 144.

The greater the strength of the magnet the greater the lifting power. This is called a direct relation.

The complete rule as stated in text books is:

The lifting power of a magnet varies directly as the square of its strength.

Varies means changes.

Directly means they both increase.

Square means multiply strength by itself.

The results in Test 2 do not seem to follow any rule. Even if the figures were changed a little as in Test 1 they could not be made so as to get a rule from them.

It is stated in nearly all text books that the lifting power of a magnet decreases according to the square of the distance from the magnet. They state the rule thus:

The attraction of a magnet varies inversely as the square of the distance.

This rule is true with very tiny magnets at small distances and in a space absolutely neutral, free from any magnetism, even the earth's effect.

Under the circumstances of ordinary life this rule is worthless.

What the test shows is this:—As you recede from a magnet the lifting power decreases at first rapidly and then more slowly.

The word *inversely* in the rule means the greater the distance the less the lifting power.

The inverse square of a number is found by squaring the number and placing it in the denominator of a fraction whose numerator is 1.

Example:

Numbers	1	2	3	4	5	6	etc.
Direct Squares	1	4	9	16	25	36	etc.
Inverse Squares	1	$\frac{1}{4}$	$\frac{1}{9}$	$\frac{1}{16}$	$\frac{1}{25}$	$\frac{1}{36}$	etc.

The peculiar thing about 1 is that 1x1 is still 1 and that the fraction 1-1 is still 1.

The importance of these laws of direct and inverse squares is greatly magnified. At the best magnets do not follow the first rule closely, and they do not follow second rule at all.

LESSON 13.

ELECTRO-MAGNETISM—CONTINUED.

Question 1. What is the "strength" of a magnet, speaking in a correct manner?

Answer. The actual quantity of magnetism flowing through one square inch of the surface of the pole piece.

Question 2. How is this quantity of magnetism measured?

Answer. Scientists have selected for a unit of magnetism a quantity they call a "line."

Their tests for the presence of "lines" and the determination of how many "lines" there are in a magnet, need not worry us, as the engineer's job is usually to produce "lines."

Take a stick of wood one inch square, wrap around it a piece of wire making one complete turn and no more. Pass a current of one ampere through this turn of wire and you will produce a flux of a little over 3 lines.

Question 3. What does Flux mean?

Answer. The term flux is used to speak about the total quantity of magnetism. For example, a designer will say that the flux from a magnet is 3½ million lines.

Question 4. What is meant by Density?

Answer. By density we mean the flux per square inch. A designer may say that both these magnets have a flux of 2 million lines; but this one having a density of 10 thousand lines has a smaller core than the other, the density of which is 5 thousand lines.

To get the flux of a magnet multiply the density by the area of the pole piece in square inches.

Knowing the flux we find the density of any part by dividing the flux by the area of that part in square inches.

Question 5. What is meant by Intensity of magnetization?

Answer. It is an out of date term among engineers. A man using the expression probably means density.

Question 6. What is meant by Magnetizing Force?

Answer. Magnetizing force or Magneto-motive force, means the force that is causing magnetism to flow out of the pole piece. In other words magnetizing force is the cause of flux.

Question 7. How is magnetizing force measured?

Answer. Since one turn of wire carrying one ampere current causes a definite flux, we use this as the unit to measure magnetizing force. It is called the Ampere turn.

Experiment shows that half a turn of wire and two amperes cause the same flux as three turns and one third of an ampere. In fact, an ampere turn is any combination of turns and currents arranged so that the number of turns multiplied by the current in amperes gives a product of one.

Question 8. Upon what does the flux from a magnet depend?

Answer. (1) Material of core.
(2) Length of core.
(3) Number of turns of wire in coil.
(4) Current in coil.
(5) Shape of magnet.

Question 9. Why does the material of the core affect the magnet?

Answer. To answer this clearly let us go back a little. A solenoid such as shown in Fig. 99 has a certain flux whose density is calculated by the following rule.

The density is equal to the number of Ampere-turns multiplied by 0.313 and divided by the length of the solenoid in inches.

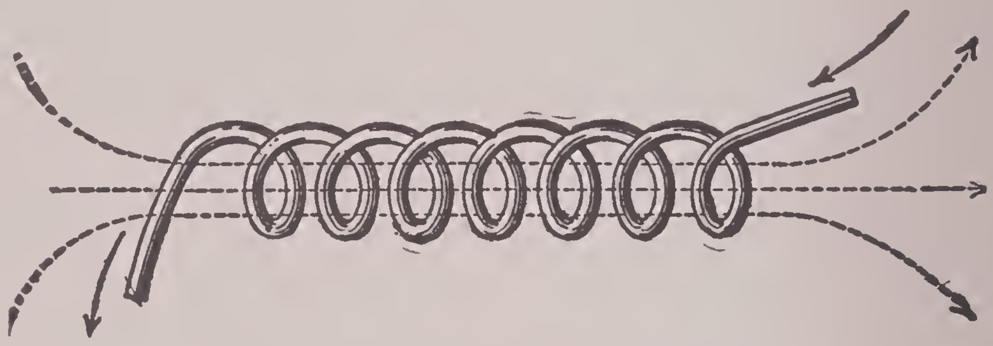

Fig. 99. Flux in a Solenoid.

If the solenoid is very short the density at the ends may be much less than in the middle.

Let us assume that we have a solenoid with a central space one square inch in area and of such a number of turns and carrying such a current that it has 3133 A. T. (ampere-turns) to each inch of its length.

Since one A. T. gives a flux of about 3 lines per square inch (see A 2), these 3133 A. T. will give a flux of 10,000 lines.

Let us take a solenoid like Fig. 99 and slip a wrought iron core into it making a magnet as in Fig. 100. Have the area of the bars' end one square inch (a bar 1⅛ inches in diameter has a cross section of practically 1 square inch).

Let the magnet have such a helix and carry such a current that there are 2.2 A. T. per inch of its length.

The flux of this magnet will be 10,000 lines.

This experiment can be completed by making a magnet of 1⅛ inch diameter cast iron rod with 18.5 A. T. per inch, and the flux will again be 10,000 lines.

It is quite evident then that the core has great influence on the strength of the magnet.

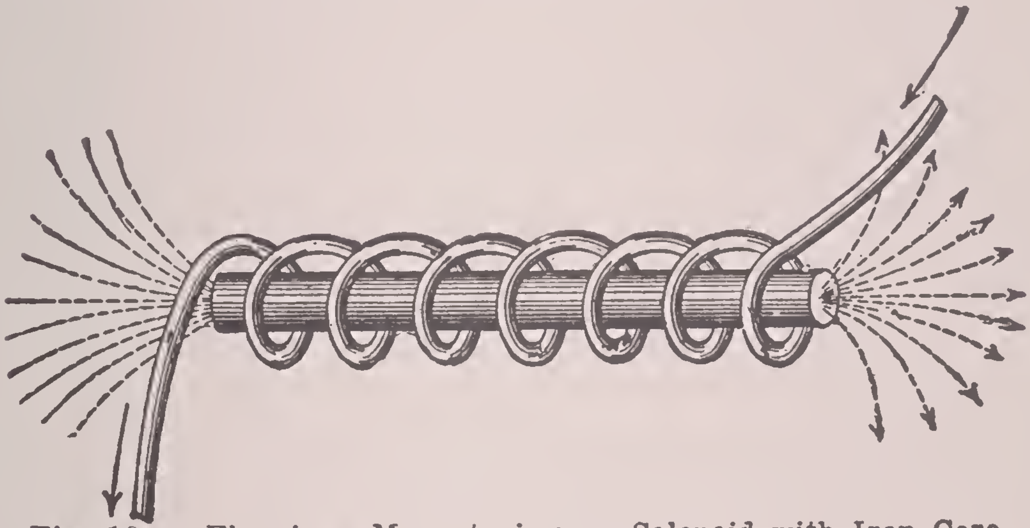

Fig. 100. Flux in a Magnet: i. e., a Solenoid with Iron Core.

The explanation is that wrought iron has far greater permeability than air and so 2.2 A. T. per inch can induce in the wrought iron as much flux as 3133 A. T. per inch could induce in air.

The permeability of cast iron being less than wrought iron it takes 18.5 A. T. to do the work that 2.2 A. T. did before.

Question 10. How does the length of the core affect the flux?

Answer. In this way 500 A. T. wrapped on an 1⅛ inch round iron* bar one inch long would give a flux of

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*When we speak of iron we mean in general wrought iron or Bessemer steel. When we mean cast iron we generally say so.

Bessemer steel is cast iron with the extra carbon burnt out. It is nearer to wrought iron than any other metal.

115,000 lines; while if the bar was 10 inches long there would only be a flux of 90,000 lines.

Question 11. Why does not the same number of A. T. give the same flux?

Answer. Because the iron although a good conductor of magnetism, offers some opposition to the flux. So if 500 A. T. can induce in a core one inch long, a flux of 11,500 lines, in a longer core it is to be expected that the flux will be less.

The magnetizing force of 500 A. T. can only do a certain amount of work and the longer the path the flux must be forced through, the less flux there will be.

To get the same flux through different lengths of circuit the A. T. per inch of circuit must be the same.

Question 12. Well then, if 500 A. T. give a flux of 115,000 lines through 1 inch of iron, why did they not give 11,500 or 1/10 of 115,000 through the 10 inch piece? Instead of that you say 500 A. T. on a 10 inch piece give a flux of 90,000 lines.

Answer. The reason is that while iron is more permeable than air the exact degree of permeability depends on the density.

500 A. T. on a 1 inch piece is 500 A. T. per inch.

500 A. T. on a 10 inch piece is 50 A. T. per inch.

Five hundred A. T. per inch can only create a flux of 11,500 per square inch because the density is so high that the iron offers a great deal of opposition to the flux, while 50 A. T. per inch, not being strong enough to create a great flux, finds the iron offering less opposition and is able to create a flux per square inch of 90,000, or nearly eight times what you would expect.

Question 13. Why does iron offer different opposition at different degrees of magnetization?

Answer. Why iron should need greater and greater increases of magnetic force to produce the same increases of density (flux per square inch) we do not know. It does not even act in any regular manner.

It is easy to show that this does occur, and perhaps we can understand the peculiar action a little from the following experiment:

Procure a thick short elastic band and a bunch of butcher's wooden skewers.

Place a dozen skewers inside the band points down. No effort is required; they practically fall in. Place another dozen in. Perhaps a gentle pressure is necessary as you begin to feel the pressure of the band.

The next dozen must be pushed in. The following dozen you have to push in one at a time. At last you will have to drive the skewers in, one at a time, with a block of wood or a light hammer.

Evidently the ease with which the skewers can be placed inside the band depends on the number of skewers per square inch you are trying to get in. As the density increases the difficulty of insertion increases.

The iron acts in the same manner. The more flux in a core the greater a magnetizing force is necessary to place additional lines in it.

Question 14. Do all magnetic materials act in this way?

Answer. Every magnetic material acts in this way in its own peculiar fashion.

Question 15. How do the non-magnetic materials such as brass, air, fibre, etc., act?

Answer. Non-magnetic materials act in an ordinary manner. Twice the magnetizing force produces twice the density.

Question 16. What statement can be made about permeability of materials?

Answer. (1) The materials which are in common use are here arranged according to their permeability at a density of 10,000 lines. The first has the greatest permeability.

(a) Annealed wrought iron.
(b) Soft steel castings. } practically equal.
(c) Cast iron with a little aluminum.
(d) Ordinary grey cast iron.
(e) Air, fibre, brass, zinc, copper. (All practically equal and very low.)

(2) At first the magnetic materials (mentioned in a, b, c, d) give more than twice the density for twice the magnetizing force. Then they change and act regularly for a short time. After this they give rapidly decreasing increase of density for equal increases in the magnetizing force, till at last a doubling of the A. T. per inch hardly increases the density. We then say the material is *saturated.*

(3) They keep the same order of degree of permeability but their actual permeabilities change in different manners.

At 10,000 density a steel casting is 5 times as permeable as grey cast iron, while at 60,000 density steel castings have 18 times the permeability of iron castings.

(4) The permeabilities of all non-magnetic materials may be taken the same as air without much error, and their permeabilities at all densities are the same.

Question 17. How can definite information as to the permeability of a metal be obtained?

Answer. A specimen is cut and tested in a laboratory. For all ordinary use the average results as published in

AMPERE TURNS REQUIRED PER INCH LENGTH TO INDUCE THE FOLLOWING DENSITIES:

A T per Inch.

Density.	Soft Iron.	Soft Steel Castings.	Cast Iron.	Air.
5000	1.7	2.	13.	1566
10000	2.2	3.7	18.5	3133
15000	2.7	4.3	24.1	4700
20000	3.5	5.	30.5	6266
25000	4.5	5.8	39.	7833
30000	5.5	6.6	50.	9400
35000	6.5	7.6	65.	10966
40000	7.5	8.8	88.	12532
45000	8.5	10.1	116.	14100
50000	9.6	11.8	160.	15665
55000	11.1	13.9	222.	17233
60000	13.	16.4	295.	18800
65000	15.7	19.3	400.	*
70000	19.6	22.7	570.	
75000	24.7	27.	*	
80000	31.2	34.		
85000	39.7	44.		
90000	50.7	57.		
95000	67.	75.		
100000	91.	100.		
105000	137.	159.		
110000	290.	325.		
115000	500.	550.		
120000	*	*		
125000				

*The figures are not given when the number of A T becomes excessively large or beyond the usual limits of density.

Air gaps are generally worked at a density below 50,000.

A density of over 105,000 is rarely used in iron or soft steel.

To find the A T corresponding to a density not given:—

How many A T per inch are required for soft steel at density of 37,000.

40000	takes	8.8	Subtract
35000	takes	7.6	
5000		1.2	Divide by 5
1000		0.24	Multiply by 2
2000		0.48	Add in
35000		7.6	
37000	takes	8.08	A T per inch.

This scheme is called interpolation and can be applied to any table.

books and magazines can be used. This table is taken from A. E. Wiener's book on dynamo designing.

Question 18. What is Reluctance?

Answer. The name reluctance is given to the total opposition offered by a piece of material to the passage of flux.

Question 19. What is Reluctivity?

Answer. Reluctivity is the reluctance of a piece of material one inch long and one square inch in cross section.

Question 20. Why are the two words necessary?

Answer. Because it is necessary to express the reluctances of magnetic circuits. It is equally necessary to express the reluctances of exactly similar pieces of different materials. To do this we would have to use the expression "reluctance per cubic inch" unless we use "reluctivity."

Question 21. Why do we not hear the word reluctivity used more frequently?

Answer. Because we usually are thinking about the conductivity per cubic inch instead of the opposition per cubic inch.

The conductivity of a piece of material one inch long and one square inch in cross section is called its permeability. It is this latter word which we use.

Question 22. What is Permeance?

Answer. The name permeance is given to the total conductivity of a piece of material for flux.

Question 23. What is meant by saying that reluctivity is the reciprocal of permeability?

Answer. When two things are opposite in sense, as reluctivity and permeability, one being the opposition, the other the conductivity, of the same piece of metal, we call them reciprocals of each other.

If the permeability of iron is 200, its reluctivity is 1/200, for the greater the permeability the less the reluctance.

Question 24. What is Retentivity?

Answer. A piece of iron becomes a magnet temporarily under the influence of ampere turns but loses nearly all its magnetism when the current is cut off from the helix.

What remains is called Residual magnetism. The residual magnetism per cubic inch is called the retentivity of the iron.

Iron or soft steel has very little retaining power; hard steel has great retentivity.

Question 25. Is residual magnetism a good or bad thing?

Answer. It depends. In dynamo armatures we would rather not have it; in the yokes of the magnets we are very glad of it.

In telegraph relays we try to reduce it as much as possible.

A peculiar thing about residual magnetism is that a piece of soft iron which has been under the influence of a magnet only a thousandth of an inch away will show less residual magnetism than if it had been in actual contact.

Telegraphers take advantage of this and paste tissue paper on the armatures of relays and sounders so that they may come very close to the magnetic cores and yet never come accidentally in actual contact.

Question 26. The word saturated was used in A 16. What does supersaturated mean?

Answer. It is possible to magnetize a piece of steel so strongly that when tested instantly after magnetizing, it shows a strength in excess of what it will show four or five hours after.

This second strength is its permanent strength. It can be magnetized permanently no stronger than this second strength, so this is called saturation.

Question 27. What is a magnetic circuit?

Answer. From experiments which were first made with permanent magnets it seemed as if the flux of a magnet simply came out of each end. Later when the result of breaking a magnet was discovered, it was recognized that the flux must also pass through the middle of the bar.

What became of the flux after it left the poles was for a long time unknown. Experiments like Fig. 80 made electricians suspect that the flux which left one pole went around through the air and entered the other pole.

In fact people soon began to believe that magnetism flows around a circuit just as electricity does.

In the case of the electric circuit it is all copper wire, while the magnetic circuit is usually composed of iron and air.

Question 28. Can you give other reasons for believing that flux flows around a circuit?

Answer. Yes. Make an electro-magnet of a ring of iron and a coil wound on as in Fig. 101 A. It will show no polarity at all, and be only slightly magnetic. Saw out a piece of the metal and the ring will develop polarity at N. and S. as shown in B.

This shows that the magnetism flowed around the ring and also across the air gap when one was made.

Question 29. Why was there no polarity in Fig. 101 A?

Answer. Because the iron being a good conductor the flux passes through it and practically none is in the air where the testing needle was put.

But if a hole should be bored in the ring and the compass dropped into it, then the polarity would show, because flux would pass through the compass.

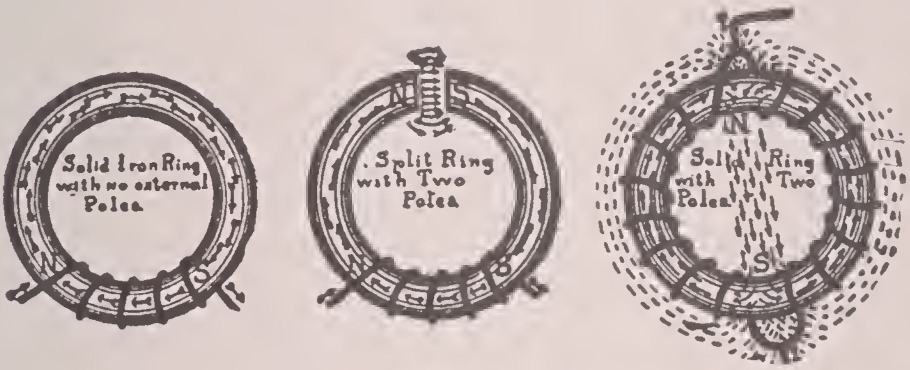
Solid Iron Ring with no external Poles
N
S
Split Ring with Two Poles
N
S
Solid Ring with Two Poles
N
S

Fig. 101. Magnetic Polarity of an Iron Ring.

Question 30. Why did Fig. 101 B show polarity?

Answer. Because the air gap being a poor conductor, the flux spread out as indicated and affected a compass needle brought near it.

Question 31. Why should Fig. 101 C develop poles at opposite sides of the ring and why should it show so much magnetism in the air around it.

Answer. The left hand part of the winding produces a N-pole at top of ring. The right hand portion does the same thing. These North polarities oppose each other and force the flux out of the iron on both sides.

Part of the flux passes directly across inside of ring to the S-pole and the rest curves around the outside of the ring through the air.

Question 32. What are closed and open magnetic circuits.

Answer. A circuit composed entirely of iron or magnetic metals is called a closed circuit, while a circuit with an air gap in it is called an open circuit. Even if the air gap is filled with brass, fibre, etc., the circuit is still an open one.

Figs. 101 B and C show open circuits. In C the iron is a continuous ring but there are two magnetic circuits each composed of a half ring of iron and an air space across which the flux passes.

The results shown in Figs. 83, 84, 85 and 86 can be explained by magnetic flux and magnetic circuits, remembering that the permeability of even hard steel is many times higher than air, which means that its reluctivity is many times less.

Suppose that in Fig. 83 only the first magnet with the nails hanging to its N-pole is present. The flux from the N-pole passes around the magnet to its S-pole. The superior permeability of the iron nails makes most of the flux pass to the S-pole through them. This makes them temporary magnets and they stick together.

Now suppose the top magnet to be slid over the under one. The permeance of the magnetic circuit composed of the two magnets lying side by side is much greater than that of the circuit composed of one magnet, the nails and all the air from the end of the last to the S-pole of the first magnet.

Naturally the greater part of the flux goes through the new path and the part of the flux through the nails is too small to strongly magnetize them. Their magnetism being reduced they cease to adhere and drop off.

The second magnet acts as a shunt circuit for the flux and being of great permeance robs the nails of the flux that magnetized them.

In Fig. 84, when only the first magnet was there, we had rather a poor magnetic circuit—a piece of steel, the nails and a long air gap from last nail to S-pole of magnet.

When the second magnet is put in position, the permeance of the circuit is improved because the air gap has been shortened. (Measure it and see.) Furthermore, in a circuit of greater permeance we have double the magnetizing force.

In Fig. 85, the adding of the second magnet increases the permeance and the magnetizing force. In Fig. 84 we reduced the air gap, while in Fig. 85 the air gap is left the same; hence the increase in inductive effect in Fig. 84 is greater than in Fig. 85.

In Fig. 86 the addition of the second magnet gives a result something like that shown in Fig. 101 C. The flux from the two N-poles which passes between the magnets is very weak and does not magnetize the nails sufficiently. The greater part of the flux goes back outside of the magnets.

LESSON 14.

LAW OF MAGNETIC CIRCUITS.

It is natural to suppose that there is some direct connection between the value of the magnetizing force and the flux induced. Also between the reluctance of the circuit and the flux induced.

These three things: the magnetizing force, reluctance, and flux are connected in the following way:

$$\text{Flux} = \frac{\text{Magnetizing force.}}{\text{Reluctance.}}$$

This formula while not of much practical use is of the highest importance theoretically. By that I mean; It is only by learning this formula by heart and understanding what it means that we can get a clear idea of how the flux in a circuit changes with the changes of magnetizing force, and how the changes of reluctance affect the flux.

Let us once more be sure that we know what the terms used mean.

Flux is the total amount of magnetism in the core, expressed as so many lines.

Magnetizing Force or Magneto-motive Force is the total pressure trying to send flux through the circuit. It is expressed by ampere turns multiplied by 1.25.

Reluctance is the total opposition offered by the circuit to the passage of flux.

The greater the magnetizing force the more flux; the greater the reluctance the less flux.

Let us see how this formula could be applied to a problem in a designer's office.

He would generally know what flux he wanted and he would know what kind of a circuit he intended to use, so he would want to find out how many ampere turns must be wound on the spools.

He must find the reluctance of the circuit. Then knowing two things he can twist the formula into this shape:

$$\text{Magnetizing force} = \text{Flux} \times \text{Reluctance.}^*$$

$$\text{Ampere turns} = \frac{\text{Flux} \times \text{Reluctance}}{1.25}$$

The reluctance of a circuit is equal to the reluctivity of the material multiplied by the length and divided by the cross section of the circuit.

This must be so because the reluctivity is the opposition per cubic inch. The longer the circuit the greater the reluctance and the greater the area of the cross section the less the reluctance.

In the first case the flux has further to travel and in the second case has more room to travel in.

Calling L length of circuit in inches and a its area, the formula becomes:

$$\text{Ampere turns} = \frac{\text{Flux} \times \text{reluctivity} \times \text{L}}{1.25 \times \text{a}}$$

This designer will not find any tables of reluctivity in books, but he can find tables or curves† of permeability. Reluctivity is the reciprocal of permeability.

---

*The way these formulas are changed will be more fully explained at the end of the lesson.

†Curves and their use will be explained at the end of this lesson.

If a man can do a job in 6 days he can do 1/6 of it in one day.

The part he can do in one day is the reciprocal of the number of days needed to do the whole job.

$$\text{Reluctivity} = \frac{1}{\text{Permeability}}$$

The formula he is using now becomes

$$\text{Ampere turns} = \frac{\text{Flux}}{1.25} \times \frac{\text{L}}{\text{a} \times \text{permeability}}$$

To make this formula more compact letters are used for the words.

Different books use different letters, some even using German or Greek letters for the names.

We will use A T for ampere turns. X (the last letter) for flux; and p (the first letter) for permeability.

The formula now looks like this:

$$\text{A T} = \frac{\text{X} \times \text{L}}{1.25 \times \text{a} \times \text{p}}$$

This is a short way of saying:

The ampere turns required to excite a magnet so as to produce a flux X are found in this way.

(1) Find the product of the flux and the length of the circuit.

(2) Find the continued product of 1.25, the area of the cross section of the circuit, and the permeability of the material.

(3) Divide the first product by the continued product.

By fussing with this formula the designer has obtained a knowledge of magnetism that can be obtained in no other way, but about this point he is apt to be disgusted with the formula. He now on looking up the permeability tables or curves finds that he must calculate the density i. e. flux divided by area before he can find the permeability he wants; for the permeability changes with the change in density.

After doing this he can replace each letter in the formula by the proper number and calculate the ampere turns.

This formula may be changed to appear as:

$$X = \frac{1.25 \times a \times p \times A\,T}{L}$$

This form is useless as a quick and accurate means of calculation for you must know the answer before you start. This is evident because *p* cannot be obtained until density is known and density is unknown until the total flux is determined.

The way to use this formula is to guess at an answer, use a value of *p* accordingly and if the answer comes out too far away from the guess, correct the value of *p* and solve again.

These formulas are not used in designing.

The designer proceeds as follows:

Suppose he has a magnetic circuit of type shown in Fig. 102. Y is the yoke which measures 12 inches between centers of holes into which the poles P. are set. The path of the flux through the poles is 14 inches long in each.

The part marked *a* is of sheet iron (annealed wrought iron sheets). The wires *w* are of copper. Between the armature iron and the pole piece on either side is an air gap of half an inch.

The magnetic circuit is through 2 × 14 = 28 plus 12 = 40 inches of steel casting. Through 10 inches of sheet iron, and one inch of air gap.

The pole pieces are, roughly, square 6x6 inches. The parts of P inside the coils or bobbins B are circular, 5 inches in diameter. The yoke is a slab 5x12 inches. Armature is 7 inches long and 7 inches wide.

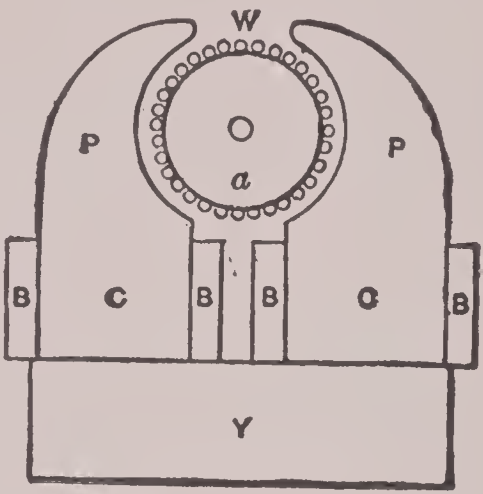

Fig. 102. The Magnetic Circuit of a Small Motor.

The flux required is 1,800,000 lines. How many ampere turns must the bobbins B contain?

From the laboratory connected with the factory he has obtained a table as is given in Lesson 13. Ampere Turns Required per Inch for Different Densities.

He figures the densities:

Yoke: 12x5 = 60 sq. in.
1,800,000 ÷ 60 = 30,000 lines.
Poles: 5 inch circles = 19.6 sq. in.
1,800,000 ÷ 20 = 90,000 lines.
Air gaps: 6x6 = 36 sq. in.
1,800,000-÷ 36 = 50,000 lines.
Armature: 7x7 = 49 sq. in.
Say 50 sq. in.
1,800,000 ÷ 50 = 36,000 lines.

Looking at the table he finds steel castings at density of 30,000 lines take 6.6 A T per inch; at 90,000 lines they require 57 A T per inch.

Air at a density of 50,000 requires 15,665 A T per inch; while sheet iron at 36,000 density needs 6.7 A T per inch.

Referring back to the lengths of the circuits and tabulating the data he has:

Material.	Density.	A T per inch.	Length.	Total A T required.
Steel.	30,000	6.6	12	792
Steel.	90,000	57	28	1,596
Air.	50,000	15,665	1	15,665
Iron.	36,000	6.7	10	67
Grand total				18,120

Since there are two coils there will be 9,060 A T on each leg of the magnetic circuit.

With a current of 1½ amperes 6,040 turns of wire will be required.

In a similar manner when a designer wishes to know the flux that a magnet will produce, he measures its area and length. He then figures from the number of turns in the coil and the current he intends it to carry what the ampere turns are. Then he figures the ampere turns per inch and looking up in the table finds the density induced. Multiplying this by the area gives him the flux.

This latter calculation can only be made when the circuit is of one material and of the same size throughout, but one makes this calculation only once to a thousand calculations of the ampere turns required.

In cases where the circuit is of varying dimensions and materials the ampere turns must be apportioned to each part of the circuit before the figuring is done.

Question 1. Suppose two pieces of Bessemer rod* each a foot long, one 1⅛ inch the other 3¾ inches in diameter, were each to be magnetized to a density of 77,500 lines (per square inch). How many ampere turns would each need?

Answer. Table says 30 A. T. per inch for density of 77,500 for soft steel. One foot is twelve inches. 12×30=360 A. T.

Question 2. But both will not require the same number of ampere turns? One is 1 sq. in. in area, the other is 11 sq. in.

Answer. They both need the same magnetizing force because the lengths and densities are the same.

Question 3. But if 360 A. T. are placed in each rod there will be a flux of 1×77,500= 77,500 in one, and 11×77,500=852,500 in the other. How can this be?

Answer. Because 360 A. T. on a 1 sq. in. rod produces 77,500 lines, but the 3¾ diameter rod having 11 times the area of the smaller rod offers only one-eleventh the reluctance and hence the flux is eleven times as great or 852,500 lines.

But as flux is 11 times as great and area 11 times larger the density is the same.

Question 4. Can you explain this in a different way?

Answer. Suppose 36 turns of wire are made in one end of a long piece; making the turns around a piece of 1⅛-inch round wood, and a 10 ampere current is sent through the whole wire. Suppose the turns are pulled apart until they are evenly spaced and the first and last turns 12 inches apart. This solenoid has now $10 \times 36 \div 12 = 30$ A. T. per inch. This will produce a density of 98 lines, say 100, in the air inside the solenoid.

---

* Bessemer rod is rolled from the same material that steel castings are poured. They are almost like iron. When purchased they have a plating of copper on them to prevent rusting.

Suppose now the whole wire is used to make the 36 turns. Keep the spacing the same but let the turns be nearly 10 inches across, from side to side. There will be an area of 78.5 sq. in. now under the influence of the solenoid.

Each square inch is just as powerfully excited as before, since there are 30 A. T. per inch surrounding it. Each of the square inches in the whole 78.5 will have 100 lines induced in it.

Question 5. Can you express this result as a rule?

Answer. No matter what the size of a core the flux per square inch (density) depends on the number of ampere turns on each inch of its length.

An expression

$$\text{Flux} = \frac{\text{Magnetizing force}}{\text{Reluctance}} \qquad (1)$$

when written

$$X = \frac{A\,T \times 1.25}{Z} \qquad (2)$$

is called an algebraic formula.

These formulas are capable of assuming different forms, but all these forms are brought about in a regular manner.

Rules may be given to teach one how to make the changes but the principle underlying the rule should be understood.

To place a term such as Z on the other side of the equal sign, remember that it must be moved either up or down. If in the denominator on one side it must move to the numerator on the other side. If in the numerator on one side it must be placed in the denominator on the other. Whole numbers are to be considered as in a numerator.

In (2) let us place Z on the left hand side of the equal sign.

$$Z \times X = A\,T \times 1.25. \qquad (3)$$

The reason for this rule is: Formula (2) must be considered as an *equation*. The left side is equal to the right side. Nothing must be done which will disturb this equality.

If we multiply both sides of (2) by Z, the equality will not be affected, and the equation will look like

$$Z \times X = \frac{Z \times A\,T \times 1.25}{Z} \qquad (4)$$

But the two Z's on the right and side cancel, and we have

$$Z \times X = A\,T \times 1.25. \qquad (3)$$

Suppose that in (2) we wished to change the formula so that the term A T would stand alone.

Z comes to the left numerator; 1.25 comes to the right denominator, and we have

$$\frac{Z \times X}{1.25} = A\,T \qquad (5)$$

Since these things are equal it makes no difference which is written first, so we write

$$A\,T = \frac{Z \times X}{1.25} \qquad (6)$$

To substitute for Z any other letter or expression, we must first be sure that the thing we wish to substitute is exactly equal to Z.

From the Lesson we know

$$Z = \frac{I}{a \times p} \qquad (7)$$

Substitute in (6) for Z its value as given in (7) by writing in the space occupied by Z the other expression:

$$A\,T = \frac{\frac{I}{a \times p} \times X}{1.25} \qquad (8)$$

The right hand side is now a complex fraction which must be simplified.

Do so in this way: Copy the numerator of the complex fraction down separately.

$$\frac{1}{a \times p} \times X \qquad (9)$$

Multiply the fraction by the whole number X in the ordinary way of arithmetic:

$$\frac{1 \times X}{a \times p} \qquad (10)$$

Go back to the complex fraction and copy its denominator changing it to a fraction.

$$\frac{1.25}{1} \qquad (11)$$

Now draw a heavy line; place (10) above it and (11) below it.

$$\left\{ \frac{\dfrac{1 \times X}{a \times p}}{\dfrac{1.25}{1}} \right] \qquad (12)$$

Multiply the extreme top and bottom of (12) for a numerator, and multiply together the middle parts for a denominator, as shown by the brackets. This gives

$$\frac{1 \times X}{a \times p \times 1.25} \qquad (13)$$

which we can put back in (8) and get

$$A\,T = \frac{1 \times X}{a \times p \times 1.25} \qquad (14)$$

Rearranging the letters we get

$$A\,T = \frac{X \times 1}{1.25 \times a \times p} \qquad (15)$$

as we did in the Lesson.

CURVES.

The use of curves in engineering work was started with an idea of showing results quickly and making them easily understood.

Suppose you were trying to impress on a man's mind the fact that the traffic on suburban trains varied in a regular manner every morning and evening, and that the through trains were evenly loaded all day. Also that the weight of the passengers in the through trains averaged 5% of the weight of the train, while the weight of suburban passengers varied from 2% to 20% of the train's weight, according to the time of day.

Hand him the following table and while the information is there it will take him some time to get it into his head. Ask him suddenly: "At what times are the suburban and through trains equally loaded with passengers?"

See how long before he finds the information which will enable him to answer.

Table of the Percentage of Passenger Weight to Light Train Weight, Grand Central Station to Mott Haven Junction, New York.

SUBURBAN TRAINS.

Time.	Percentage.	Time.	Percentage.
Midnight	2.	6	12.
1	2.25	7	18.
2	2.75	8	20.
3	3.	9	18.5
4	3.5	10	14.5
5	5.	11	9.

Time.	Percentage.	Time.	Percentage.
Noon	8.25	6	19.
1	8.5	7	19.25
2	8.75	8	16.
3	9.5	9	10.5
4	11.	10	6.5
5	16.	11	4.25
Midnight	2.		

THROUGH TRAINS.

Five per cent at all hours

Now hand him the following curve (Fig. 103):

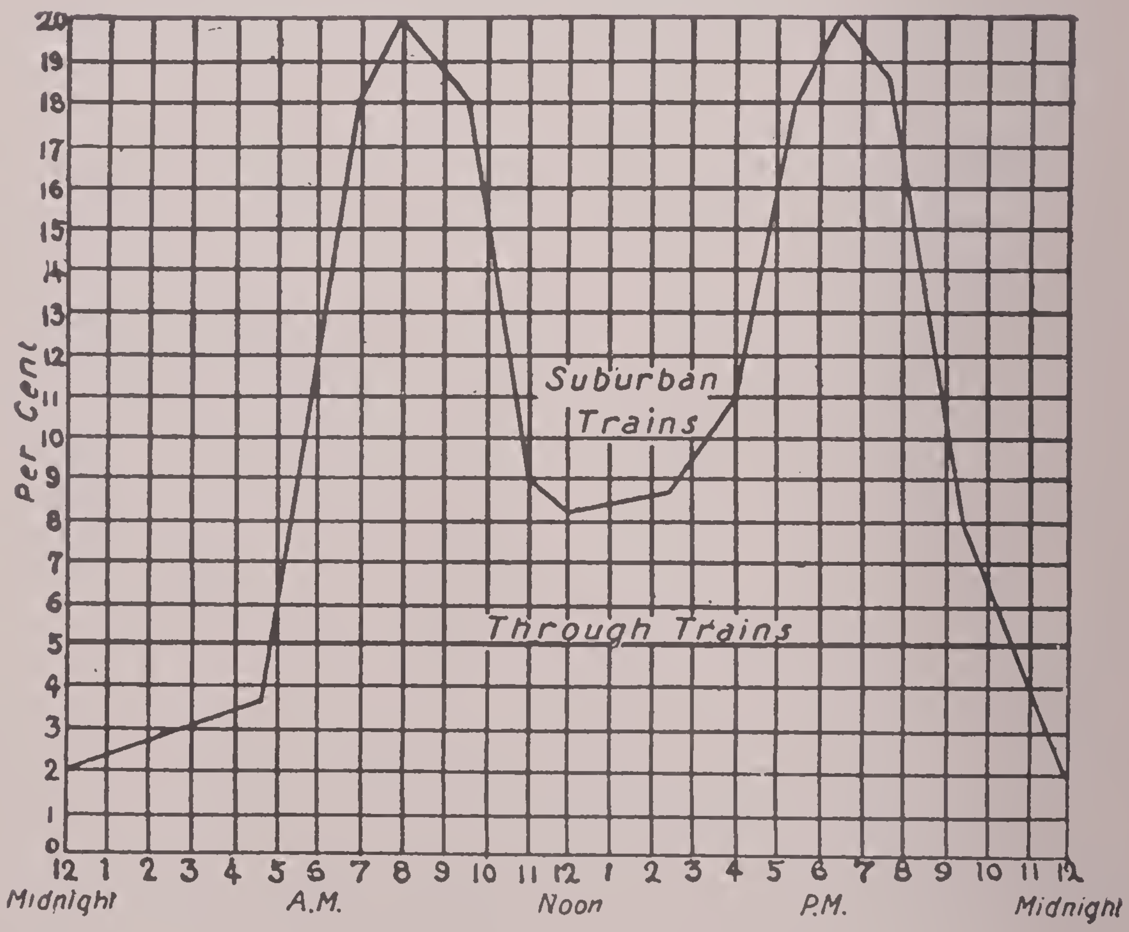

Fig. 103. Percentage of Passenger Weight to Total Weight of Train.

How quickly he grasps the way in which the traffic varies. He notices much more quickly than he would by use of the table that from 5 to 8 in the morning there is an abrupt rise in traffic, while from 6:30 to 11 in the evening there is an equal decline in traffic at a much slower rate. He notices the great changes in train loads between 5 and 7 in the morning and the slight change between 2 and 4 in the afternoon.

Ask him again the question, and see how quickly it is answered.

A curve is certainly a great thing for imparting information.

The curve is drawn from the table in the following way: Procure a piece of paper printed with lines running across at right angles in both directions and at some convenient distance apart, say 1/10 of an inch, or for finer work, 1 millimeter.* This is called cross-section paper.

Determine which of the set of two numbers you are most anxious to have show up strikingly, and number each line up along the left edge accordingly.

Each space can be 1%, but if the percentages run up very high, you might have to call each space 5%.

Number the lines along the bottom of the sheet according to hours. Let one space represent 15 minutes or one-quarter of an hour, or if there is not room for this, let each space count one hour. When the lines are properly numbered, lay out the curve.

Place your pencil on the first vertical line (marked midnight). Run pencil up along this line until you reach the horizontal line marked 2%. Make a dot where these two lines meet.

---

* A millimeter is 1/10 of a centimeter, i. e. about 0.04 of an inch.

On the next line, marked 1 a. m., run the pencil up till opposite a point one quarter the way up between the 2 and 3% lines. This represents 2.25. Make a dot here.

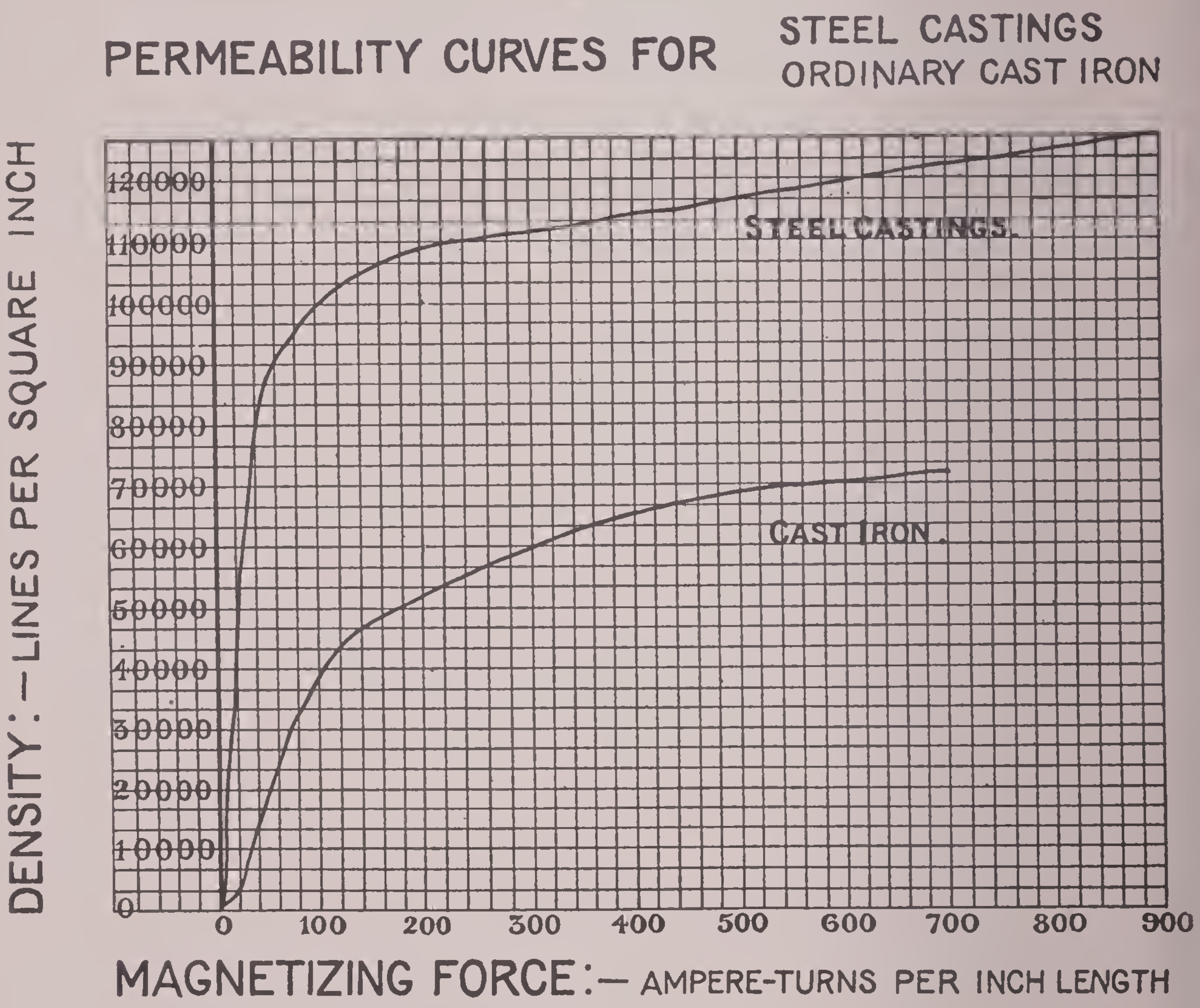

Fig. 104. Permeability Curves.

With the figures from the table in this way make a dot at the point where the vertical time line cuts the horizontal per cent line.

There will be one dot for every set of figures in the table. When all dots are placed, draw a line through them and you have the desired curve.

Figure 104 contains two curves drawn from data obtained from the table of ampere turns per inch at different densities.

Certain information can be more easily gained and is shown in a more impressive manner by these curves than by the table.

Notice that as you steadily increase the A. T. per inch on a steel casting at first the result is a great increase in flux, and the density rapidly increases, but after a while the density increases very slowly.

With cast iron this same statement is true, but the effect is not so marked. At first you get a rapid increase in density and later a slower increase.

The first and last parts of the steel curves are practically straight lines. Designers often speak of the "straight line portion of the curve." The part between these two is called the "knee" of the curve.

The cast iron curve has no definite straight line portions and the knee is so large that it is difficult to exactly locate it.

LESSON 15.

PRIMARY BATTERIES.

There are many places where we need a small amount of electrical power, so little that running a line to the point would not pay. In such cases we uses batteries.

A storage cell needs more attention than a primary cell, so many automatic signals, call bells, and such are operated by primary cells.

There is a deal of truth in the statement, "There is electricity in everything." The hard job is to get it out.

Suppose you throw a dozen shovelfuls of fine damp coal into the firebox, and forget to close the door. The result you get is not the fault of the coal. It was full of B. T. U.'s[1] and you gave them a chance to get out, but not in the proper manner, and they failed to do the work of making steam.

What a difference there is if this same kind of coal in larger pieces is fired two shovelfuls at a time with just the right quantity of air.

So it is with electricity; we must treat our materials in exactly the correct manner if we expect a production of current worth the money expended.

If one pound of zinc be placed in dilute sulphuric acid[2] it will dissolve and give out 1,026 B. T. U., but no electricity. You will notice that there are bubbles of hydrogen gas coming up from the zinc and a thermometer would show the increase in temperature. A certain part of the energy liberated might have been obtained as electricity if the zinc were treated in the following way:

---

[1] B. T. U. is an abbreviation for a British Thermal Unit, being the amount of heat required to raise one pound of water from 39 to 40 degrees Fahrenheit (ordinary thermometer). One pound of good coal contains 1,200 B. T. U.

[2] Buy *oil of vitriol* and dilute by pouring the acid slowly into 20 times as much water, stirring with a piece of glass. An earthen ware pot is the safest thing to mix in as the great heat generated will not crack it.

Placing the zinc and a piece of copper in a jar of dilute sulphuric acid, not allowing them to touch below the liquid, allowing them to touch above it, or connect them with a copper or iron wire. Now the thermometer will rise very little, electricity will flow through the wire and the wire exhibit magnetic qualities. We agree to say that the current flows from the copper to the zinc outside of the cell and from the zinc to the copper in the liquid.

We have now started into action the simplest of the primary batteries.

This same experiment made with a strong solution of common salt in water will work as well.

If you attempt to use the current from such a simple cell you will find that it is very quickly apparently exhausted.

To be a commercial success a cell should deliver current more or less continuously until its zinc is all consumed.

In the words "more or less continuously" lies the distinction made between cells. An "all around service" cell is difficult to design, so that we have Open circuit, Semi-closed and Closed circuit types of cells.

The main thing in any cell is to avoid the tendency of the cell to "lay down" while there are yet plenty of chemicals in the cell capable of, under proper circumstances, delivering electricity.

This stoppage of the cell's activity is called Polarization.

Return to the simple cell of copper, zinc and sulphuric acid. If it has been used long enough to "lay down," examine the plates. The copper one is entirely covered with bubbles. These are the cause of the cell's non-action. The cell is polarized. The reason for this name and the cause of the non-action will be best understood by first learning this table:

TABLE OF VOLTAIC CELL MATERIALS.

Direction of current through the wire in external circuit. ☜

Positive	Z	I	L	C	S	C	Negative
	i	r	e	o	i	a	
Plates	n	o	a	p	l	r	Plates
	c	n	d	p	v	b	
				e	e	o	
				r	r	n	

Direction of current through solution in cell. ☞

This table is the result of experiments such as you can perform yourself. In another glass of dilute sulphuric acid place two pieces of zinc and connect them. They dissolve but no electricity is delivered. Try two iron plates with the same result, with perhaps less corrosion of the metal by the acid. Two pieces of lead give no electricity and are hardly affected by the acid, while two sticks of carbon are not even attacked by the acid. With zinc and iron you get a weak and almost useless cell, with current flowing from the iron to the zinc. Zinc and copper we know to be good, but we find that zinc and carbon is better.

This table is evidently arranged so that the further apart the metals stand in it the better a cell they make.

This should set you thinking. A zinc plate and a bubble covered copper plate will not make a cell. Therefore bubbles must make a positive plate.

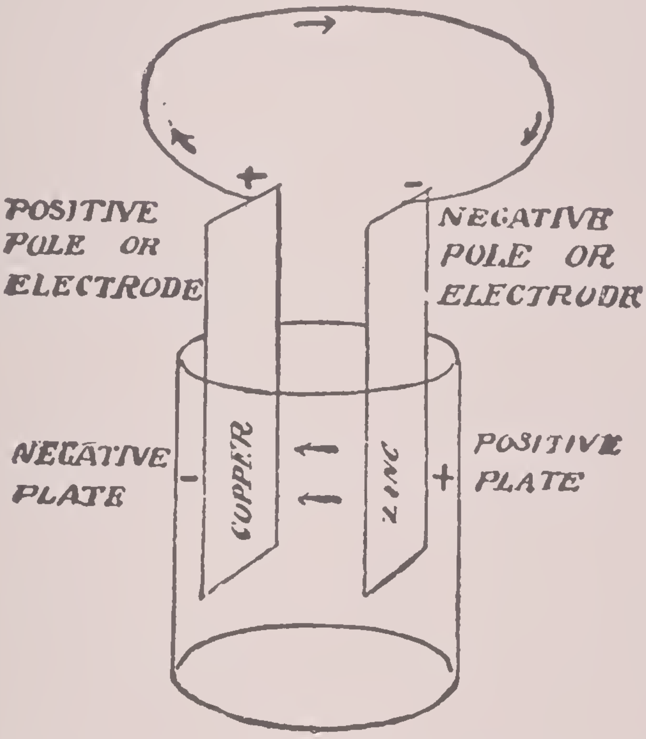

Fig. 105. Names of Parts of Cell.

You must find now what the bubbles are and how they act electrically.

The things in the cells are:

Zinc: that is zinc and impurities.

Copper: that is copper, pure.

Sulphuric Acid: that is sulphur, hydrogen and oxygen.

Water: that is hydrogen and oxygen.

Since the bubbles are of gas they must be either hydrogen or oxygen.

Chemistry books will tell you that oxygen makes a fine negative plate and hydrogen a fine positive plate; just about as good as zinc.

The cell has then two positive plates in it, and has two negative poles. (See Fig. 105.) The cell is polarized.

We have learned so far that a cell must have two different materials immersed in a solution and the more rapidly it attacks one and the less it affects the other the better the cell. For this reason zinc and carbon, being cheap commercial products, are almost universally used in primary cells.

Also a cell to be a commercial success must either not produce hydrogen gas or get rid of it after production.

We will now describe some of the most used cells, classifying them under headings as follows:

Open circuit: A cell designed for intermittent work. Periods of work short, intervals of rest long. Usually designed for small currents. When not in use these cells must be left on open circuit.

Semi-closed: A cell designed for fairly steady work. Periods of work long, intervals of rest short. Often designed to produce heavy currents. When not in use these cells must be left on open circuit.

Closed circuit: A cell designed for continuous work. Periods of work long, intervals of rest very short. Usually designed for very small currents. Almost impossible to design so as to produce much current. When not in use they must be left on closed circuit.

Polarization prevented: Cell so designed that no hydrogen gas is produced by chemical action of cell.

Polarization cured: Cell produces hydrogen, but a chemical placed in the cell turns the hydrogen to water, which is harmless.

Polarization delayed: Cell has very large and absorbent negative plate.

CELLS COMMONLY USED IN RAILROAD WORK.

The Carbon Cylinder Cell. These are sold under the name of Law, Samson, Hercules, etc. It is an open circuit, polarization delayed type. They give a pressure of 1.5 volts and have a resistance of 1 to 2 ohms. Two of them are shown in Fig. 106.

The carbon element is made with as large a surface as possible. Carbon and charcoal have a remarkable power of absorbing gases. A cubic inch of charcoal will condense and absorb 20 to 30 cubic inches of gas.

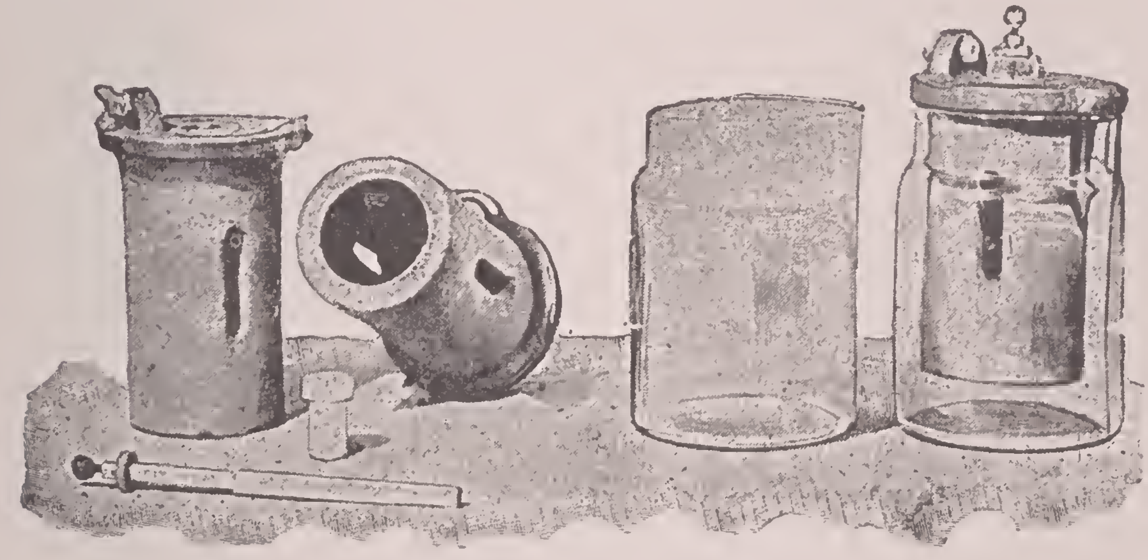

Fig. 106. Carbon Cylinder Cell.

The zinc element is a rod and the fluid a strong solution of sal ammoniac in water. The scientific name of this chemical is ammonium chloride.

The action of the cell dissolves the zinc, forming zinc chloride, which dissolves in the water. A little ammonia and hydrogen gases are set free. The ammonia is dissolved by the water and the hydrogen absorbed by the carbon.

In time the carbon gets soaked full of hydrogen, and to restore the cell it should be taken out and boiled in water for an hour.

These should only be used for call bells in offices or such unimportant work.

Leclanche Cell. This is an open-circuit, polarization cured type. They are made in several forms. Voltage 1.5 and resistance 1 to 4 ohms. Uses sal ammoniac, zinc and carbon.

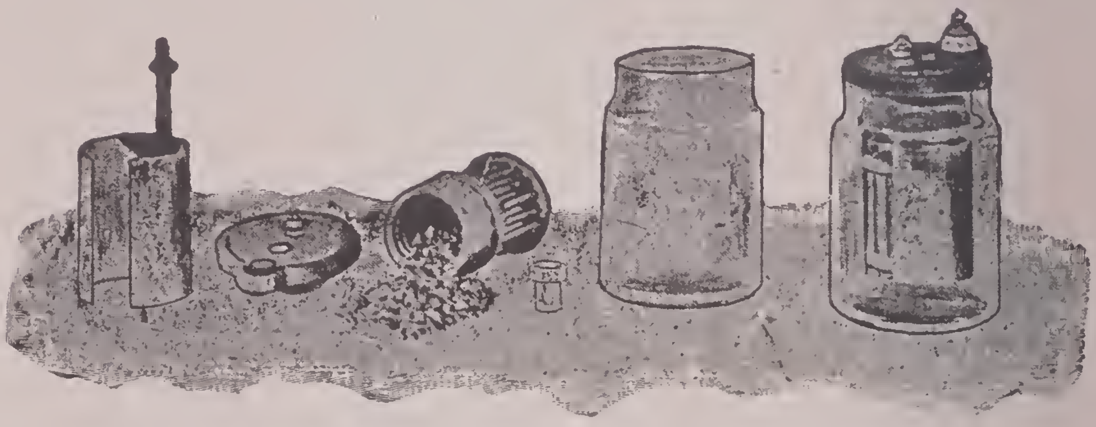

Fig. 107. Carbon Cylinder Cell with Depolarizer.

The carbon cylinder cell is sometimes modified to the Leclanche type by making the carbon element with a bottom and no opening in the sides. This carbon can or bucket is filled with lumps of black oxide of manganese (manganese dioxide). The zinc is made in a cylindrical form, surrounding the carbon. This cell is shown in Fig. 107.

The hydrogen is absorbed by the carbon but the manganese dioxide, being in contact with the carbon, gives up half of its oxygen to the hydrogen forming water, while it is reduced to manganese monoxide.

This cell is useful for call bell work, operating magnets on interlocking machines, running tell-tales on interlocking boards and such other intermittent light work.

There is an older form of Leclanche cell shown in Fig. 108, where the carbon is placed in a cup of unglazed earthen ware (like a yellow flower pot) called a porous cup. The manganese is packed around the carbon slab. This form does not give such a large current as the cell in Fig. 107 because its resistance is high, often as much as four or five ohms.

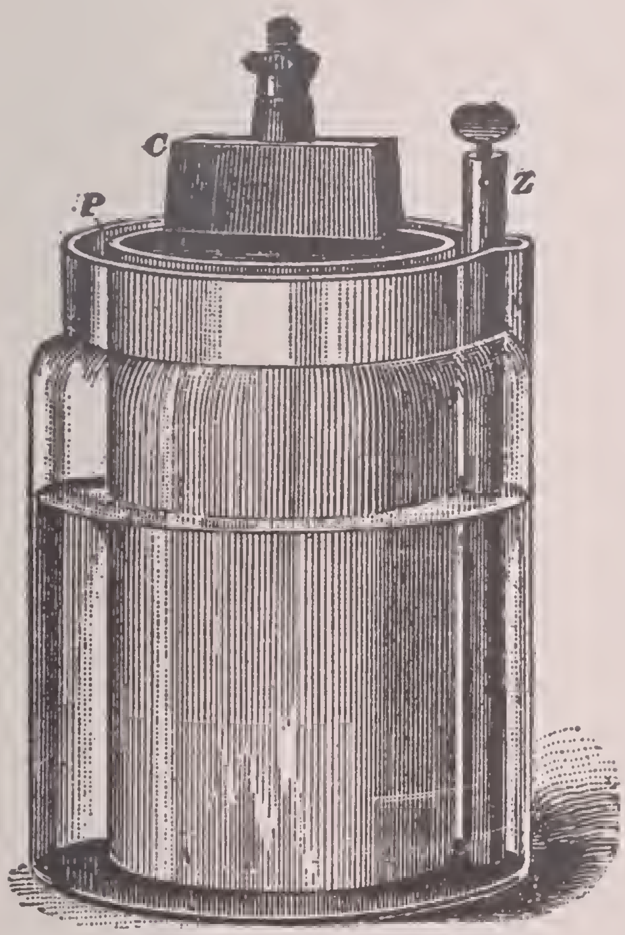

Fig. 108. Ordinary Leclanche Cell.

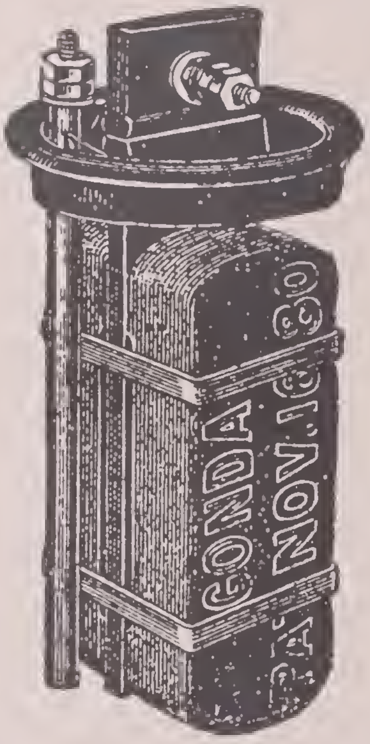

Fig. 109. Elements of the Gonda-Leclanche Cell.

A much used form of the Leclanche cell is the Gonda cell. The elements are shown in Fig. 109.

Here the manganese is powdered, mixed with cheap molasses. then by heat and pressure formed into slabs.

These are attached to the carbon plates by rubber bands.

The bother and resistance of the porous cup is avoided.

The usual charge of a Leclanche type cell is a generous quarter pound of sal ammoniac dissolved in sufficient water to fill the jar two-thirds full after elements are in place.

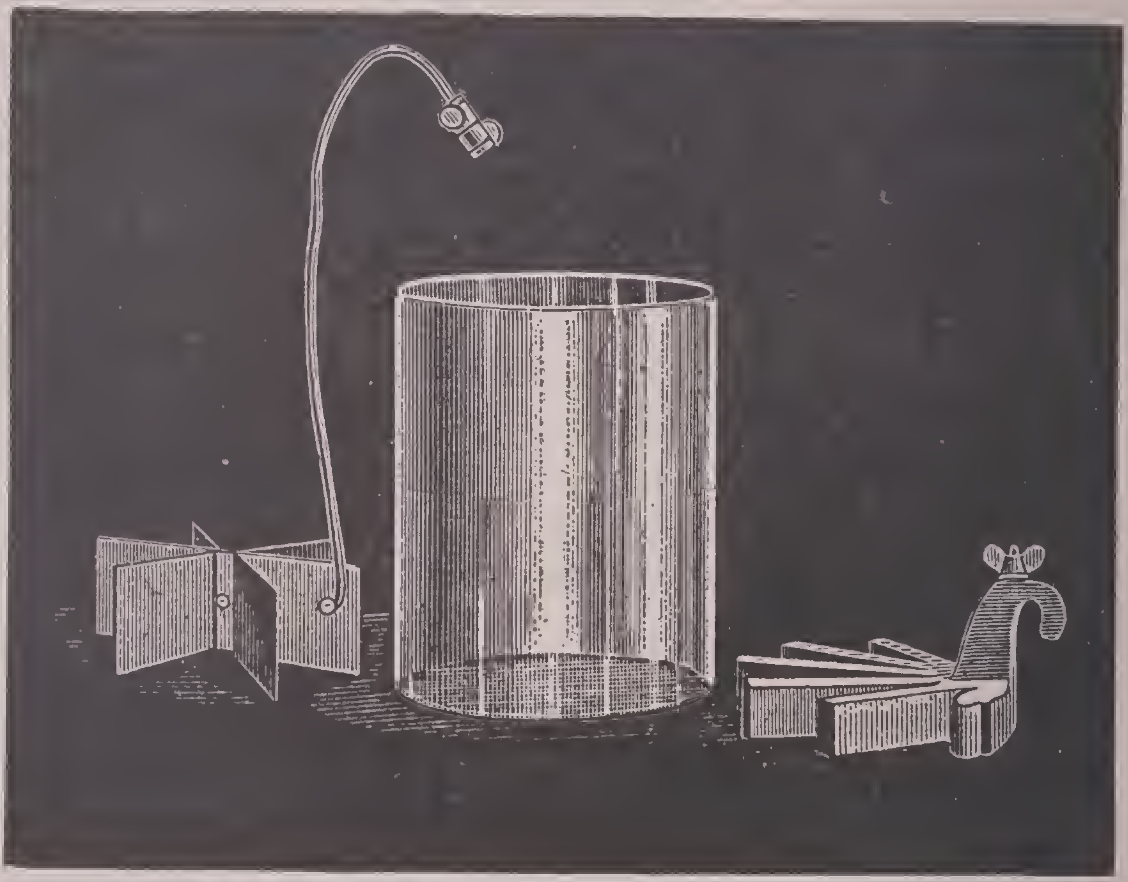

Fig. 110. Elements of Gravity Cell and Jar.

The Gravity Cell. This is a closed circuit cell with polarization prevented. It is very much used for telegraph circuits, operating the electrical devices in the lock and block signals, the motors in automatic signals and generally around interlocking plants. Its pressure is 1 volt and its current capacity rather low for its resistance is 3 or 4 ohms.

This cell is made in many forms called Bluestone cell, crow-foot battery, Lockwood cell, etc.

The parts of a gravity cell are shown in Fig. 110, and the assembled cell in Fig. 111.

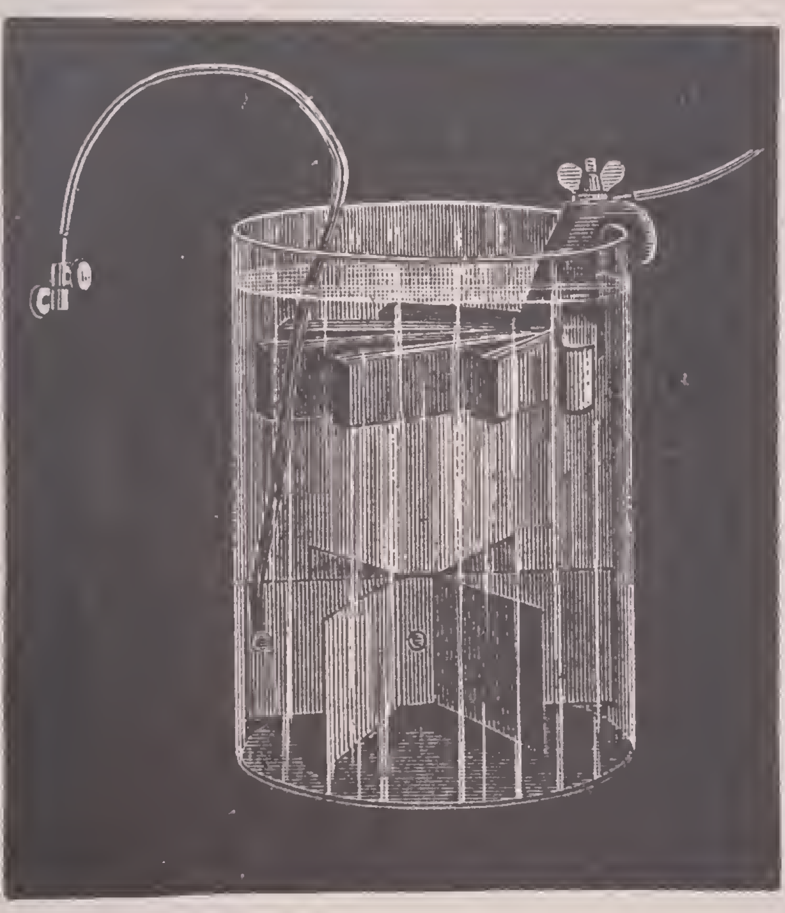

Fig. 111. Gravity Cell Ready for Use.

The glass jars should be about 7 inches high and 6 inches in diameter. The zinc is cast in a shape so as to be easily suspended from the edge of the jar. The form shown is called a crow-foot zinc. It weighs about 3 pounds.

The copper element shown on left of Fig. 110 is made of three sheets riveted together at center and then spread out as shown. The rubber covered wire must be attached to the copper element by riveting. If soldered the joint would be eaten away by electrical action.

To set up a cell of ordinary size which holds about 0.8 gallons of liquid make two solutions, one of copper, the other of zinc.

Zinc solution: Pint and a half of pure soft water and 10 oz. of crystallized sulphate of zinc (white vitriol). Mix until dissolved and let it stand half a day in a glass jar.

Copper solution: Two and a half pints of soft water, 4 ozs. of crystallized sulphate of zinc, 8 ozs. crystallized sulphate of copper (blue vitriol). Mix and let stand a few hours in a glass jar.

Dip edge of battery jar for an inch in melted paraffin and let it cool.

Place the parts in jar as in Fig. 111 and pour jar nearly three-fourths full of the zinc solution. Place it at once in the spot where it is to be used and pour in the copper solution.

Insert a glass funnel in the top of a piece of ⅜-inch rubber tubing. Hold funnel so that lower end of the tube will be in the middle of the jar and just a little above the bottom.

Pour in the copper solution slowly until the copper element is completely covered. Place the cell into service immediately.

This cell will show a sharply defined line between the blue copper solution and the colorless zinc solution. This separation of solutions is essential to the cell's health. Leaving the circuit open for any length of time will allow the solutions to mix and spoil the cell.

The action of the cell is such that no hydrogen is permanently formed. The zinc is steadily dissolved into the zinc solution, setting free some hydrogen. This forms with the copper sulphate, sulphuric acid and metallic copper. The sulphuric acid dissolves more zinc, while the copper plates itself on the copper element at the bottom of jar.

The zinc is consumed and the copper plate grows larger.

The effect of continued action is to increase the strength of the zinc solution so that it tends to settle to bottom of jar.

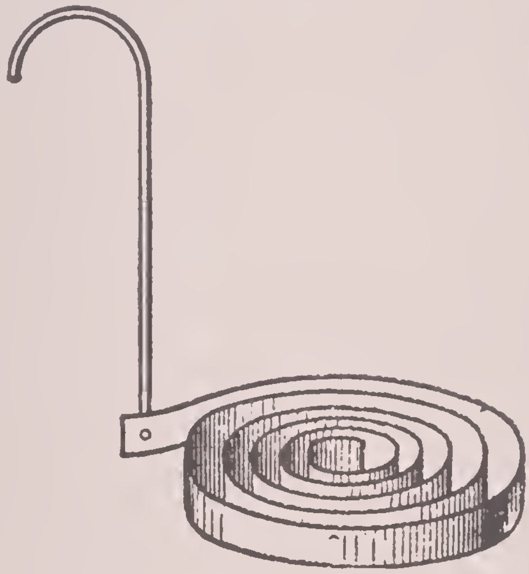

Fig. 112. Long Service Copper Element for Gravity Cell.

The copper being taken out, bit by bit, from the copper solution this latter gets lighter in weight and tends to rise, being pushed up by the zinc solution.

If the blue solution of copper sulphate ever touches the zinc it will copper plate it at once. The cell will then have two copper elements and stop working.

Cells should be given some attention, and clever management will keep a gravity cell working continuously for an almost indefinite time.

As helps in the maintenance of cells two improvements have been made.

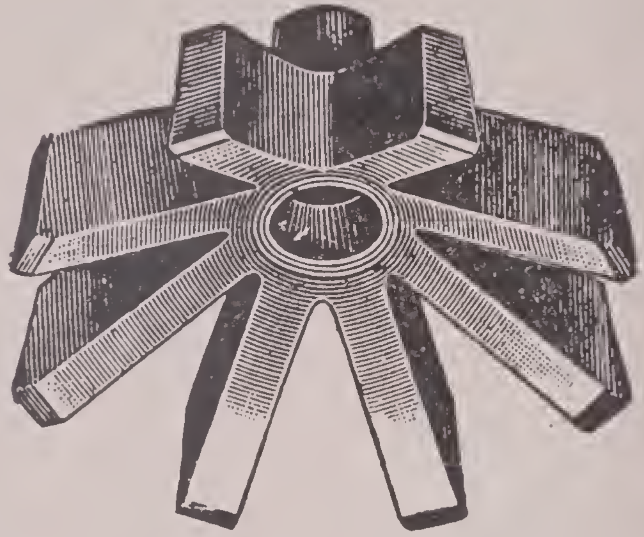

Fig. 113. d'Infrevilles Wasteless Zinc.

The form of copper element shown in Fig. 112 is better when heavy currents are not needed. It is a copper ribbon 4 feet long and ½ an inch wide, coiled like a clock spring. Zincs shaped like Fig. 113 are used until the prongs are all eaten off. A new one is then put in

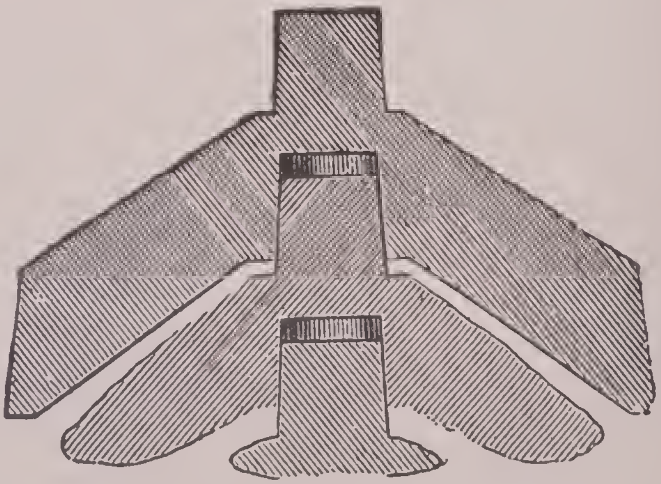

Fig. 114. Using Up Old Zincs.

service and the old one jammed into the bottom of the new one as shown in Fig. 114.

These zincs are hung from a spring clip shown in Fig. 115, which lays across the top of the jar. The stud on the zinc makes a tight friction fit with the hole in the hanger, due to the springiness of the metal.

To keep cells in order a hard rubber syringe with the nozzle at right angles to barrel, holding about a pint, and a hydrometer should be obtained.

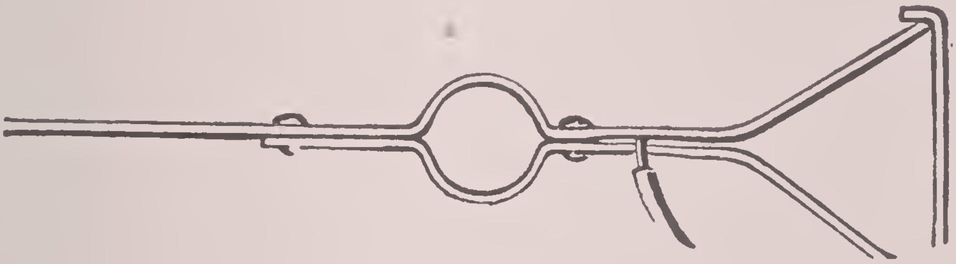

Fig. 115.

The hydrometer (Fig. 116) is a hollow glass float loaded with shot so as to float upright. The heavier a liquid the more of the stem sticks up above the surface.

These hydrometers are graduated on stem in actual specific gravities or in degrees Baume (pronounced Bomay). One with a stem about two inches long graduated from 15° to 40° Baume, or from 1.11 to 1.40 specific gravity, is best for battery work.

The first signs of exhaustion in the cell will be a fading of the deep blue color of the copper solution and a lowering of the line of separation between blue and white liquids.

When this occurs drop in about an ounce of copper sulphate in lumps. Be sure the lumps fall to the bottom.

There will always be a lot of fine powder at the bottom of the copper sulphate barrel. Use this for making up new cells when possible. If too much accumulates for this purpose, make a saturated solution of it in water.

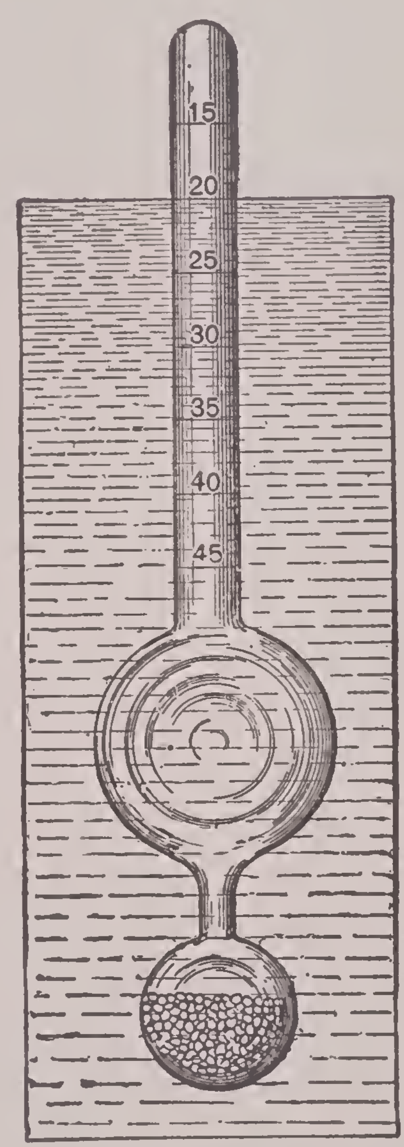

Fig. 116. Hydrometer with Baume Scale.

A saturated solution is one where the water has dissolved all it possibly can of the chemical and leaves some yet undissolved on bottom of jar after repeated stirring.

Place this in cells showing signs of exhaustion in same way as the copper solution was placed in a newly set up cell.

The zinc solution should be tested as frequently as possible. Once in two weeks is not too often. Drop the hydrometer gently in. Should it read 115 draw some out with syringe and replace by fresh water.

Do not let it go below 1.10. If you have a Baume scale these numbers are 20 and 15 degrees. Throw all the removed zinc in a wooden tub, whether from working cells or from old cells, to be renewed.

Keep half a dozen pieces of metallic zinc in this tub. Any copper in this solution, mixed by cell's action, will turn to a reddish brown curd which can be filtered out. Reduce the clear liquid to 1.10 and use in making up new cells.

Watch your zinc. Should any brown hangers develop on it, detach them with a bent wire and let them fall to bottom of cell.

In time, in spite of all care, the zinc in a cell gets reddish brown all over. It is now time to give a complete overhauling.

Take the cell out of service. Syphon off zinc solution into the tub. Lift zinc out carefully and at once scrub clean with a wire brush. Wash and replace in another cell at once or dry thoroughly and keep dry until needed.

Syphon off the rest of the liquid into another wooden tub and use after filtering as copper solution to make up new cells.

Any lumps of copper sulphate in the bottom take out, rinse and put in other cells.

The mud in bottom of cells and in the zinc solution tub should be dried and sold to brass founders as "battery mud."

The copper plates taken from cells should be kept completely covered with water, wire and all, until needed again.

When they get too heavy and cumbersome sell them, as they are an especially pure form of copper.

Never leave gravity cell on open circuit; the liquids will mix.

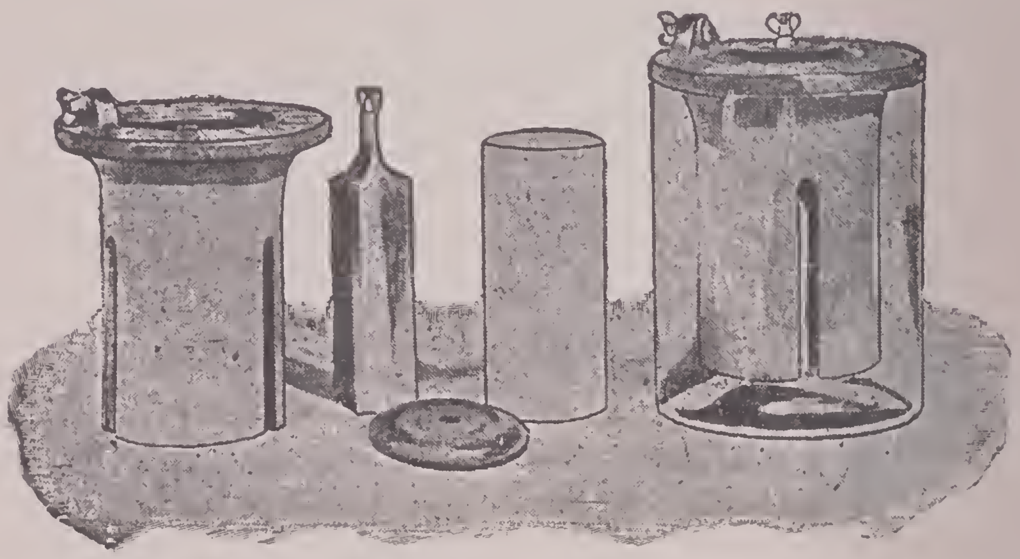

Fig. 117. Fuller Cell.

The Fuller Cell. Semi-closed circuit type, for heavy duty. Long periods of work with little rest.

Polarization cured. Pressure 2 volts, resistance 0.5 ohms. Cell shown in Fig. 117.

These cells are carbon and zinc, and since the chemical which converts the hydrogen to water will attack the zinc, a porous cup is used.

The carbon or the zinc can be placed in the porous cup, but the zinc usually is. A tablespoonful of mercury is placed in bottom of porous cup, the zinc set in and the cup filled with very dilute sulphuric acid (1 acid, 50 water). The carbon is then placed in the outer jar, the porous cup being also in, and the outer jar filled three-quarters full of battery fluid or electropoin.

This is composed of 4 ozs. of bichromate of soda, 1¼ pints of boiling water, mixed and cooled; then while slowly stirring add little by little 3 ozs. sulphuric acid taken out of a carbon (not diluted). NEVER POUR WATER INTO ACID.

The bichromate of soda has so much oxygen in it that it will turn the hydrogen to water, changing itself to chromate of soda.

When the interior of the porous cup gets dark green colored a cup should be soaked in 1 to 50 acid for an hour and then mercury placed in bottom and zinc set in. Simply take out old cup and insert new one in its place.

The old zinc should be cleaned, porous cup washed and then boiled in water and both placed in stock.

These cells should be left on open circuit when not in use. They are very powerful, but nasty to handle and not as cheap as the gravity cell. When the electropoin gets greenish it soon becomes exhausted, then throw it away. Cold battery rooms or pits affect this cell less than the gravity cell.

Edison-Lalande Cell. This is a semi-closed type with polarization cured. It has a resistance of 0.2 ohms and a very low voltage, 0.7, but is a bull dog for holding on. It will, when set up, start in to deliver a heavy current and keep at it until all its chemicals are used up. It needs no attention and is built so that you can not give any.

When it stops take out the copper and sell it, throwing everything else out. Clean up the jar and fit out again.

The cell uses zinc and oxide of copper plates immersed in a solution of caustic potash. The oxide plate is shown in Fig. 118 and the complete cell with a glass jar in Fig. 119. Porcelain jars are usually furnished.

The caustic potash comes in sticks sealed up in a tin can.

Place the elements in jar and fill with water to about one inch of the top. Take out the elements and put in the sticks of potash.

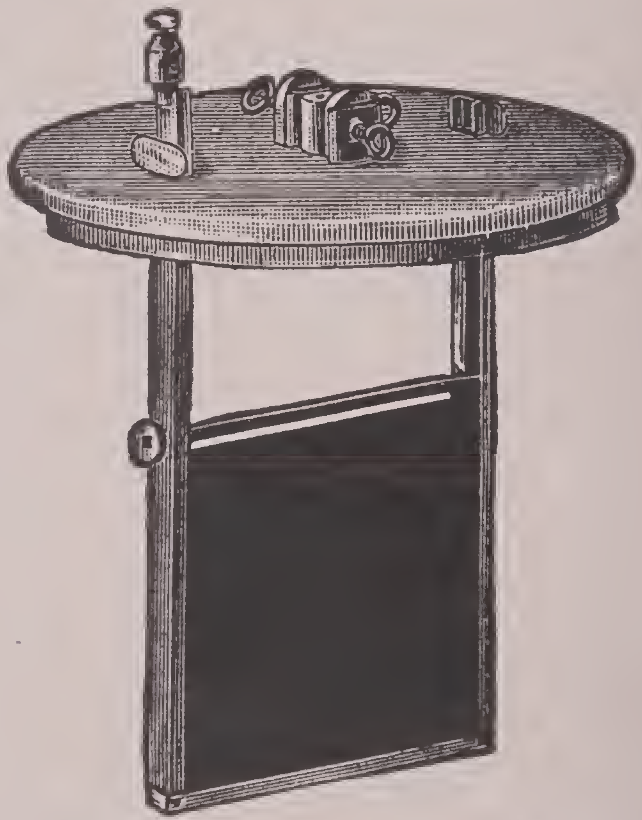

Fig. 118. Oxide Plate of Edison-Lalande Cell.

Stir constantly while dissolving, for it gets very hot and might crack the jar. Be very careful not to get caustic potash on your flesh. It not only burns terribly, but makes a wound which is very hard to heal.

If you buy potash by bulk, make the solution up to 1.33 on specific gravity scale or 38° on the Baume scale.

Place the zinc and copper oxide elements in the jar, seeing that they are properly separated by the hard rubber buffers. Pour the bottle of oil over the top of solution and place cover on.

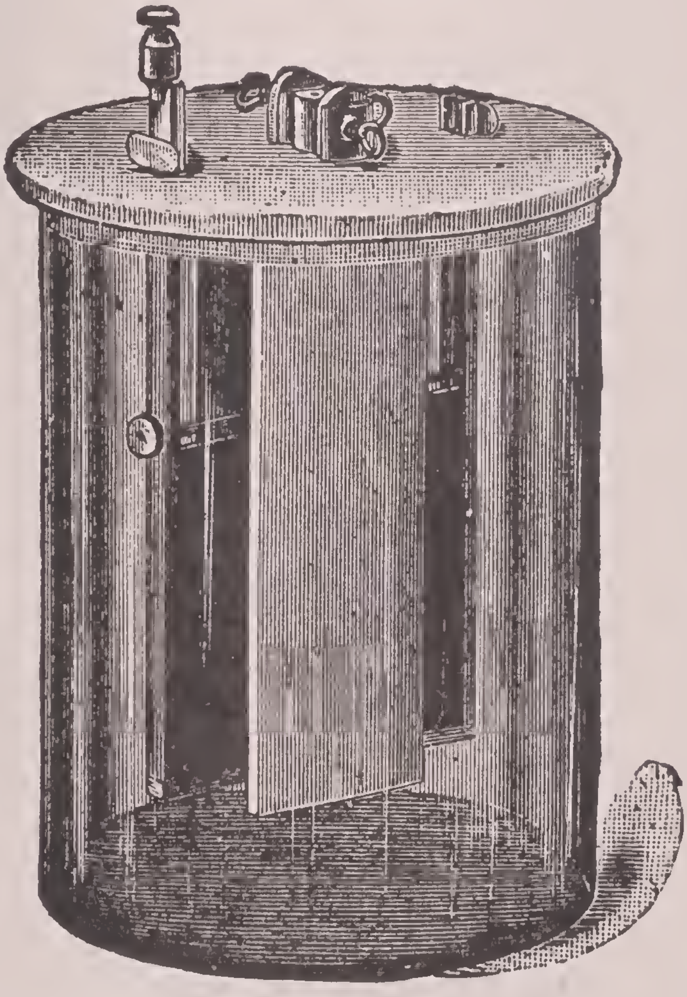

Fig. 119. Edison-Lalande Cell.

If buying oil by bulk, get a heavy paraffin oil which will read 1.46 specific gravity on 48° Baume and pour a ¼ inch layer on each cell.

These are good cells, but any sulphuric acid or caustic potash cell is a nasty thing to handle.

The action of the cell dissolves the zinc, setting free hydrogen, which is changed to water by the copper oxide, which is reduced to pure copper by giving up the oxygen in it.

The Dry Cell. Shown in Fig. 120 is really a moist cell sealed up water tight with cement or glue.

The can is made of zinc and serves as one element, while a carbon plate or rod is the other. Around the carbon is packed a mixture of powdered manganese dioxide, carbon and flour, while the rest of the can is filled with a mixture of plaster, oxide of zinc and flour; the whole being soaked with a solution of sal ammoniac and zinc chloride. Pressure 1.4 volts.

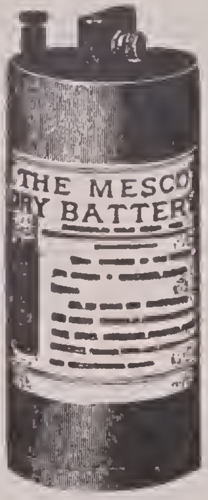

Fig. 120. Dry Cell.

These are very useful for testing, as they can be carried around in a satchel or your overcoat pockets.

Whenever they are used in sets see that their resting place is dry, otherwise the moisture will connect all the zinc cans together and cause them to run down.

The principles on which primary cells work are simple and well understood by most people; yet there are men trying yet to design a cell to do more than is possible.

The best that could be done with a cell using zinc as the dissolved metal is to get one horse-power-hour* per pound of zinc.

There are inevitable wastes which prevent us doing as well as that, so with coal at ¼ cent a pound and zinc at 16 cents it is evident that the primary battery will only be used when circumstances force us to use it.

One great waste is Local Action:

Local Action. Commercial zinc or *spelter* contains small particles of carbon and iron which with the zinc they are imbedded in form small *local cells* producing electricity where it cannot be gotten at for use, and the zinc is continuously dissolved whether the cell is on open or closed circuit. In the sal ammoniac batteries sometimes the change in the strength of the solution will cause the zinc to be eaten through at or very near the surface of the solution.

The remedy for this is

Amalgamation. Mercury forms a soft paste or amalgam with all the metals except iron, and will not dissolve carbon. Advantage is taken of this fact and *local action is prevented* by cleaning the zinc with sand paper, washing with dilute sulphuric acid, and while wet rubbing on mercury (quicksilver) with an old brush or a rag tied to a stick. N. B. Mercury is a poison. The zinc becomes bright, covered with a layer of zinc-mercury amalgam; and the particles of iron and carbon are merely covered up and protected from the acid, which cannot corrode the mercury. During the action of the cell the zinc dissolves out, and the mercury eats its way into the zinc, reforming the amalgam. When the zinc around the particles is eaten away they fall out to the bottom of the battery jar and do no harm. Zincs for batteries are sometimes cast with 5% of mercury in them. When the zinc is in a porous cup it is a good thing to pour a tablespoonful of mercury into the cup and then set the amalgamated zinc in. With all the precautions that can be taken about 3% of the zinc put in the cell is wasted in local action.

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* An horse-power hour is the work done by a one horse-power engine running at full load for an hour; or the work done by a 10 H. P. engine running at half load for one-fifth of an hour, etc.

CATECHISM TO LESSON 15.

1. What is an open circuit cell?

2. What is a closed circuit cell?

3. What is polarization?

4. What means are used to prevent polarization?

5. What ways are there of curing polarization?

6. What two materials of ordinary cost make the best cell?

7. How good a cell would zinc and iron in sal ammoniac make?

8. Would the results of a zinc silver combination in sulphuric acid give results worth the cost?

9. What is the name of the wet end of the zinc element? The dry end?

10. What is the name of the wet end of the copper or carbon element? The dry end?

11. Why would not a zinc-copper cell made like a Law cell operate?

12. What cells would work well on a signal circuit closed 98% of the time?

13. What cell would work well on the motor of a signal, current closed 1% of the time?

14. What is Local Action?

15. What is amalgamation of zinc?

16. How are zincs amalgamated?

17. What is a hydrometer?

LESSON 16.

STORAGE BATTERIES.

The storage cell is rapidly pushing the primary battery aside in signal and fire alarm work on account of:

(1) Its high voltage.

(2) Its great current capacity.

(3) The lowering of total battery expense if used for several years.

(4) Its steadiness of action.

Storage cells are used in train lighting to furnish light when train is not in motion and to steady the supply of current.

They are used in some cases to furnish the power to operate switches on locomotives and motor cars.

In power houses they offer a reserve supply of power and act as a steadier of the load on the generators.

The simplest storage cell would be two strips of lead immersed in dilute sulphuric acid. When current is sent through them one plate turns a dark brown color and the other a grey color. After an hour's passage of current reverse the connection and charge the other way. The plates will change color—the grey one becoming brown and the other one grey.

If this charging first in one direction and then in the other be kept up, you will notice that after each reversal of the current through the cell the acid is quiet but soon begins to gas or boil. This is the signal to reverse the current as the cell is charged.

When the cell takes several hours to gas it is in condition to use.

After one of the reversals continue to charge until cell has gassed about fifteen minutes. Remove the charging wires and connect to anything you wish to run. About 70% of the power you put into the cell can now be taken out.

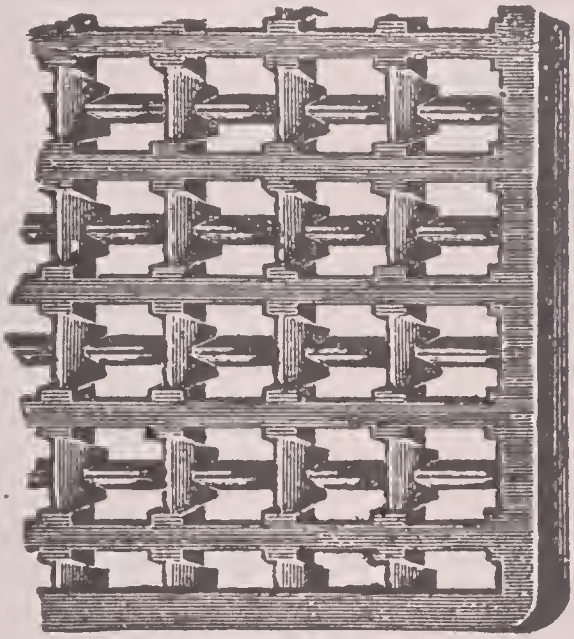

Fig. 121. Lead Grid.

You may now use this as a storage cell, charging it up till it gasses and then using the accumulated electricity as you please.

You always lose 30% but you have the advantages of portability and ability to work when engines are shut down.

In time you will notice that the lead plates become spongy and should the cell be used long enough the plates will finally crumble and break. You will notice that the more spongy the plates become the greater a charge they are capable of holding.

In fact, just before your battery goes to pieces its capacity is the greatest.

To make a commercially practical cell we would proceed thus:

The lead plates would be replaced by grids as shown in Fig. 121 or by grooved plates as in Fig. 122.

Litharge and sulphuric acid is mixed to a stiff paste and the grids or grooved plates plastered with the paste and stood up to dry. This makes a negative plate.

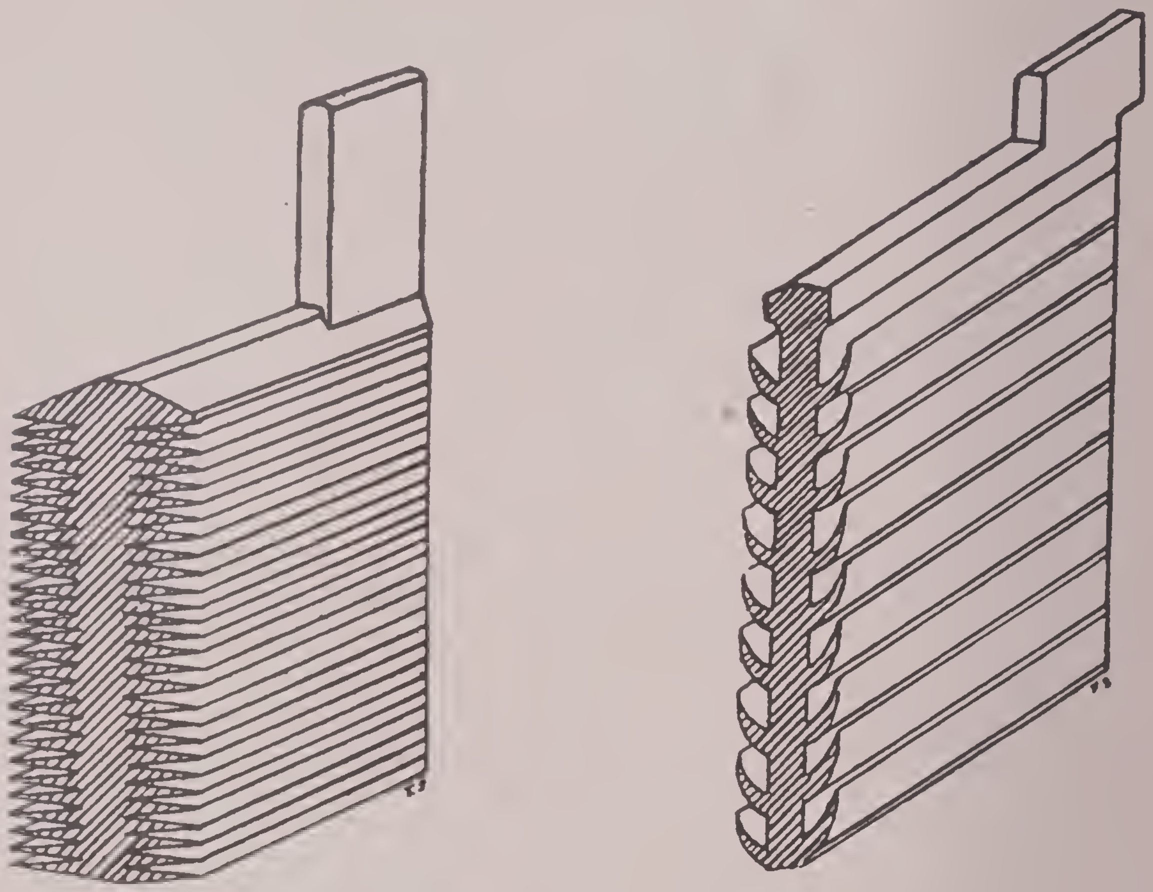

Fig. 122. Grooved Lead Plates.

Using a paste of red lead and sulphuric acid the positive plates are formed in the same way.

The objection to a storage cell using these plates is that after very little use they go to pieces. The changing of the red lead to the brown oxide, and the changing of the litharge to spongy lead is accompanied by a swelling and shrinking of the material. This loosens up the pasted mass and it begins to fall out.

Most of the ingenuity of inventors has been concentrated on making plates which would hold the active materials firmly and continually.

Perhaps one of the best lead-lead (i. e. lead for both plates) is the Electric Storage Battery Company's Chloride Cell.

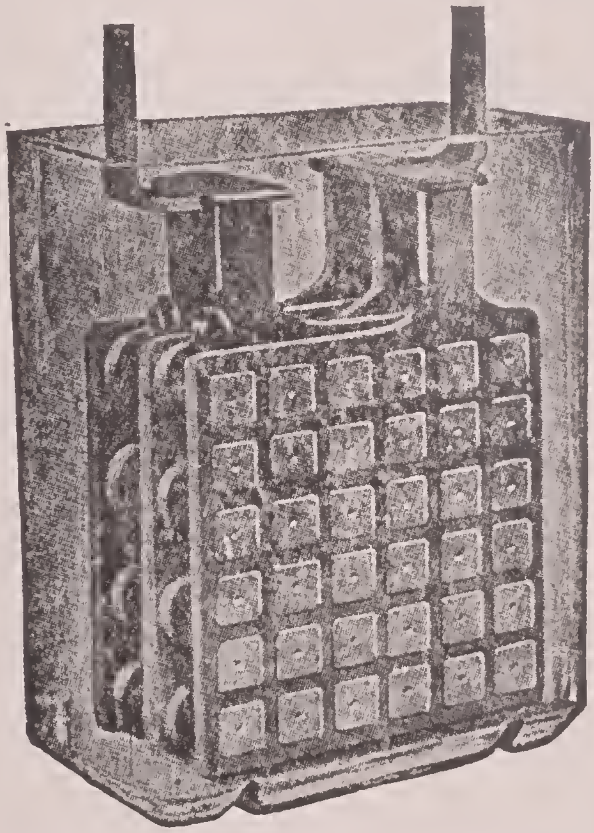

Fig. 123. Chloride Accumulator.

This cell is shown in Fig. 123. Its method of manufacture is interesting and is practically as follows:

The first thing is to get finely divided lead which is made by directing a blast of air against a stream of the molten metal, producing a spray of lead which upon cooling falls as a powder. This powder is dissolved in nitric acid and precipitated* as lead chloride on the addition of hydrochloric acid. This chloride washed and dried forms the basis of the material which afterwards becomes active in the negative plate. The lead chloride is mixed with zinc chloride, and melted in crucibles, then cast into small blocks or tablets about ¾ inch square and of the thickness of the negative plate, which according to the size of the battery varies from ¼ inch to 5/16 inch. These tablets are then put in molds and held in place by pins, so that they clear each other 0.2 inch and are at the same distance from the edges of the mold. Molten lead is then forced into the mold under about seventy-five pounds pressure, completely filling the space between the tablets. The result is a solid lead grid holding small squares of active material. The lead chloride is then reduced by stacking the plates in a tank containing a dilute solution of zinc chloride, slabs of zinc being alternated with them. The assemblage of plates constitutes a short-circuited cell, the lead chloride being reduced to metallic lead. The plates are then thoroughly washed to remove all traces of zinc chloride.

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*Turned back to a solid.

A later form of negative plate consists of a "pocketed" grid, the opening being filled with a litharge paste; this is then covered with perforated lead sheets, which are soldered to the grid. The positive plate is a firm grid. composed of lead alloyed with about 5% of antimony. about 7/16 inch thick, with circular holes 25/32 inch in diameter, staggered so that the nearest points are .2 inch apart. Corrugated lead ribbons 25/32 inch wide are then rolled into close spirals of 25/32 inch in diameter, which are forced into the circular holes of the plate. By electrochemical action these spirals are formed into active material, the process requiring about thirty hours; at the same time the spirals expand so that they fit still more closely in the grids. This form of positive is known as the Manchester Plate.

In setting up the cells the plates are separated from each other by special cherry wood partitions, the perforations being connected by vertical grooves to facilitate the rising of the gases. Sometimes glass rods are used as separators.

There are ten sizes of cell, the smallest containing three plates 3 by 3 inches, and the largest having seventy-five plates 15½ by 30¾ inches, ranging in capacity from 5 to 12,000 ampere-hours, and in weight from 5½ to 5,800 lbs. The smaller sizes are provided with either rubber or glass jars, and the larger one with lead-lined tanks.

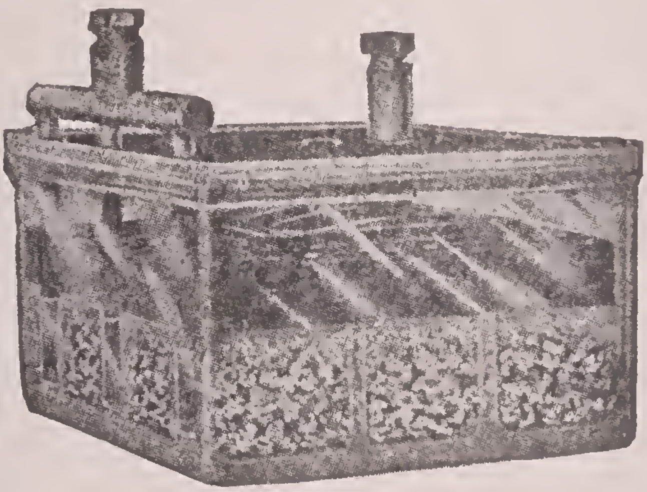

Fig. 124. Lead-Zinc Storage Battery.

In the lead-lead cells the negative plates deteriorate in capacity, while the positive plates increase in capacity, with continued use.

To even things up the two end plates are made negative and they then alternate, thus giving one more negative plate per cell.

A lead-zinc cell is made by the United States Battery Co. It is shown in Fig. 124.

The positive plate is of perforated lead sheets riveted together with lead rivets and formed by the slow process of charging and reversal as described in first part of lesson. The negative element is a zinc amalgam which swells up when charged.

This amalgam lies on bottom of jar while the lead element hangs over it.

The pressure given by these cells is a little higher than a lead-lead cell and they weigh less for the same capacity. For signal work they are excellent, while for reserve power use the lead-lead cell is preferred as being better under such severe conditions.

The Edison Cell uses grids of nickel plated iron, the grids being filled with small nickel plated steel boxes which are perforated with very small holes.

The boxes in positive plate are filled with oxide of nickel and pulverized carbon, the negative boxes being filled with oxide of iron and pulverized carbon.

The carbon in each case is merely to render material a better conductor.

A 20% solution of caustic potash is used in a nickel plated steel vessel.

The advantage of this cell is its lightness and ability to stand the most reckless abuse. For railway work it is no better than any other cell and its price puts it out of consideration.

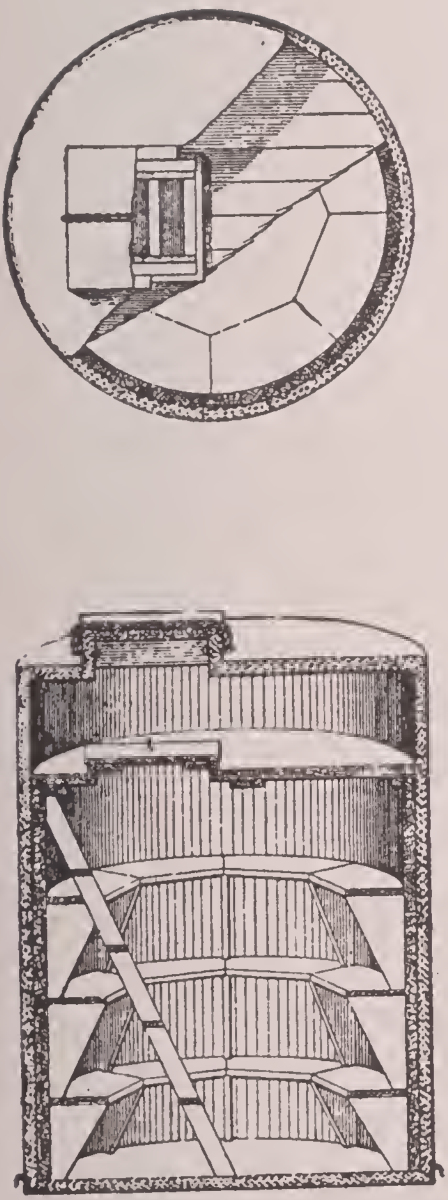

Fig. 125. Top and Inside View of a Concrete Battery Well.

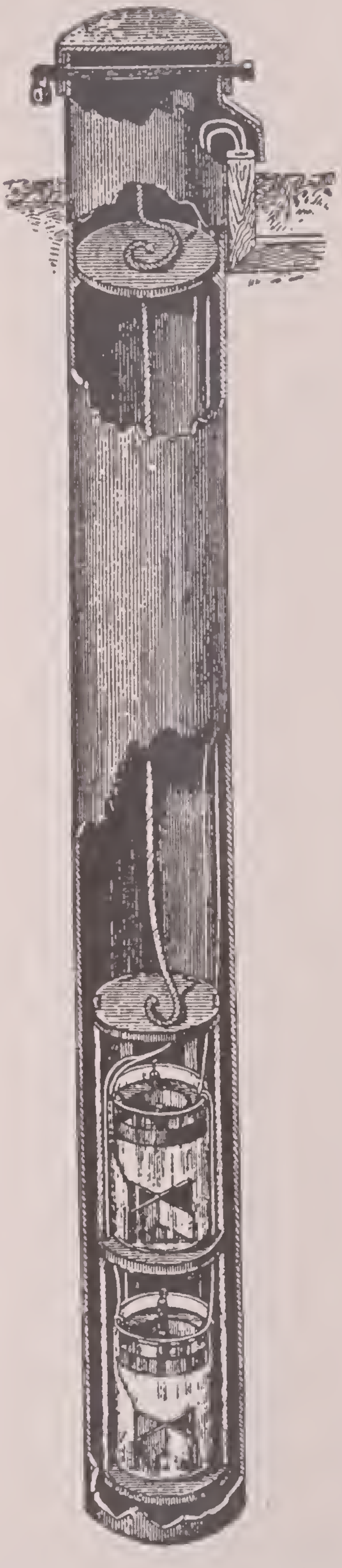

Fig. 126. Battery Chute.

CATECHISM.

Question 1. What is a storage battery?

Answer. It is a cell somewhat resembling a primary cell, used to store electricity.

Question 2. Does the cell produce electricity or simply store it?

Answer. The chemicals in the cell are not normally capable of producing electricity but by treating them with electric current for some hours they become changed so that they can produce electricity like a primary cell. In fact we might say that a storage battery is a primary cell which, when exhausted, is restored to its original power by application of electric current which renews the chemicals, whereas in the ordinary primary cell we have to buy new chemicals. The gravity cell can be renewed a few times by passage of current, but soon gets in a condition where purchase of fresh chemicals is absolutely necessary.

Question 3. Of what material is the positive plate made?

Answer. Red lead is the real plate, but it is supported by a lead grid.

Question 4. What material is used for the negative plate?

Answer. Spongy lead or litharge, held in a lead grid. Zinc in form of amalgam lying on a copper plate.

Question 5. What fluid is used in jars?

Answer. Dilute sulphuric acid.

Question 6. What is sulphuric acid?

Answer. It is an oily liquid either colorless or with a very faint yellow tinge. It is sold in carboys* as Oil of Vitriol and should test by hydrometer (Lesson 15) to 1.842 specific gravity or 66 degrees Baume.

To avoid the constant use of the decimal point battery attendants call the strong acid 1842 acid and call water 1000 specific gravity.

Question 7. What is dilute acid?

Answer. It is acid of 1842 strength mixed with pure water. To make 1200 acid take 1 measure of acid and pour into 3 measures of water. For 1400 acid take 1 measure acid and pour into an equal quantity of water. 1200 acid is most used and corresponds to 25° Baume.

Question 8. Is pure water necessary?

Answer. For best results, yes. Distilled water is not so very expensive to make and it pays. Half of the battery troubles are caused by filling up cells with any clean water that is handy.

Even clean water contains chemicals that should not get into the storage battery.

Question 9. Should the diluted acid be cooled before putting in cells?

Answer. It should be thoroughly cooled. Acid should always be diluted the day before you intend to use it. The specific gravity should be taken after acid has cooled at least twelve hours.

Question 10. Does it make any difference whether 1200 or 1400 acid is used?

Answer. Yes. Acid from 1150 to 1230 is generally used. The stronger the acid the greater the capacity of the battery and the more liable it is to get the disease of Sulphate.

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*Carboys are large glass bottles several feet high and about the same diameter. They are securely boxed to prevent breaking.

Question 11. Why is it that the acid tested in cells is sometimes so high?

Answer. The acid is weakest when cell is discharged and strongest when cell is charged. This is because the acid goes in and out of the plates on discharge and charge.

Question 12. What is meant by a 180 ampere-hour cell?

Answer. It means that the cell in question will give 1 ampere for 180 hours, if it has been fully and properly charged. It might give 30 amperes for 6 hours if it was designed for allowing the flow of such a current.

It certainly would not give 180 amperes for 1 hour as the heat generated would buckle the plates and ruin the battery before the end of the hour.

Question 13. What is the normal rate of a battery?

Answer. As batteries are usually made we may draw 1 ampere from every 10 square inches of positive plate, counting both sides, without over heating.

A cell of 5 positives and 4 negatives, has plates 5x7 inches. What current is it safe to draw? 7x5=35=one side of a plate. Both sides 70 sq. in. 5 plates gives 350 sq. in. Dividing by 10 gives 35 as safe current. This is called the normal rate. In actual practice we usually discharge at about normal rate and hurry the charge by exceeding the normal rate.

Question 14. What harm does this do?

Answer. Wastes money. It costs more to put in 180 A H (ampere hours) quickly than it does slowly.

Question 15. What is an 8 hour rate?

Answer. It means taking 8 hours to charge or discharge the battery. If battery is worked twice as hard it will charge or discharge in half the time or at a 4 hour rate.

Question 16. What precaution should be taken in a battery room?

Answer. The room must be dry and well ventilated to get rid of the acid fumes. Walls and floors should be of enameled brick and ceiling of white cement. Windows should be white-washed on outside or of ground glass to prevent sun shining on cells and heating them.

The benches cells stand on should be soaked in paraffin. The cells should stand on insulators.

Question 17. How are signal batteries installed?

Answer. In wells like Fig. 125 when there are many. These wells are of sheet steel and concrete, and are about 10 feet high. They are heated when necessary by small oil stoves or by being packed over the top with manure.

When only two or three cells are used the battery chute of Fig. 126 is installed. The chute is of iron pipe and goes down below the frost line. The cells are hauled up by the rope for renewal or charging.

Question 18. Of what material are battery jars made?

Answer. Glass, hard rubber, celluloid, wood with sheet lead lining.

Small cells usually have glass jars as in Fig. 127. Large cells have the lead lined wooden tank as in Fig. 128. Hard rubber and celluloid are expensive. Neither is transparent.

Question 19. How should cells be put in service?

Answer. As soon as electrolyte (acid) is put in the cell it should be charged with one-third its normal rate for 4 hours, then increase to normal rate and continue 20 hours. Cells will now be up to 2.6 volts each.

Drop back to one-quarter normal rate. The voltage of each cell will drop a little. Continue charging up to 2.6 volts again.

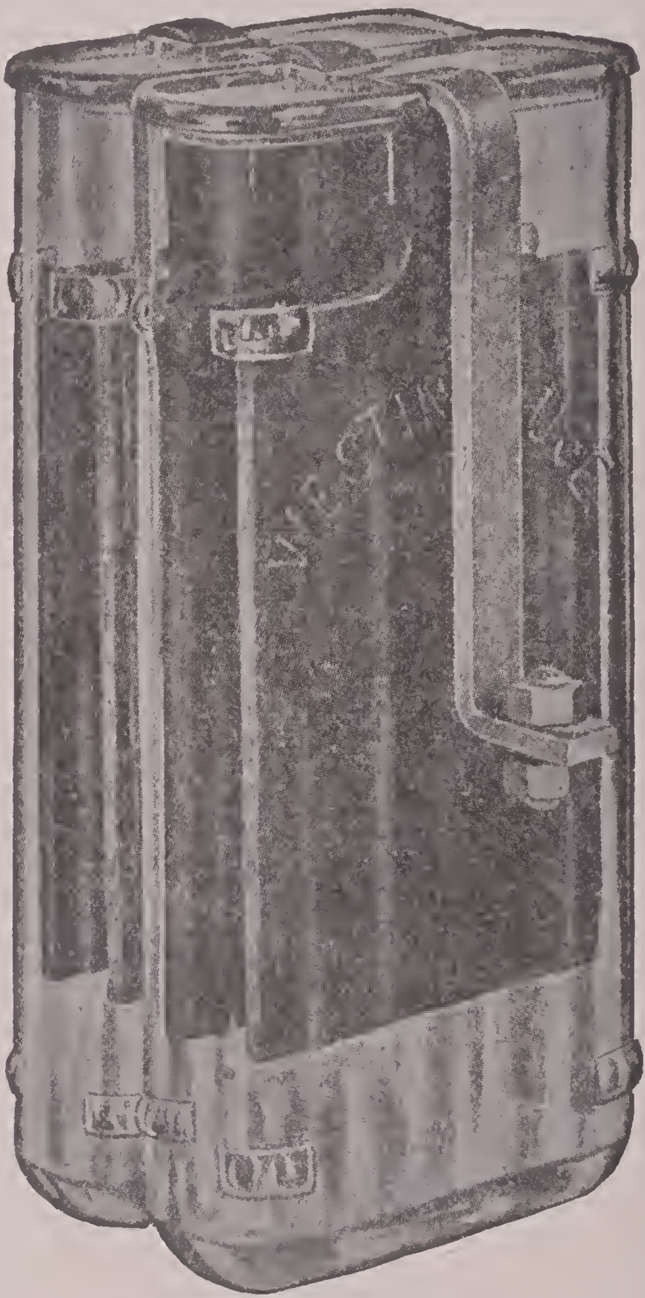

Fig. 127. Form of Storage Battery for Signal Work. Glass Jar.

Question 20. How should cells in service be treated?

Answer. Never discharge below 1.7 volts and 1.8 is better. Charge up to 2.5 volts usually at normal rate.

Once a week give a charge at one-third normal rate till cells read 2.6 volts.

Never let them stand idle with less than 30% of their capacity in them. The fuller a cell the safer it is when idle. When cells are idle charge up to boiling once a week.

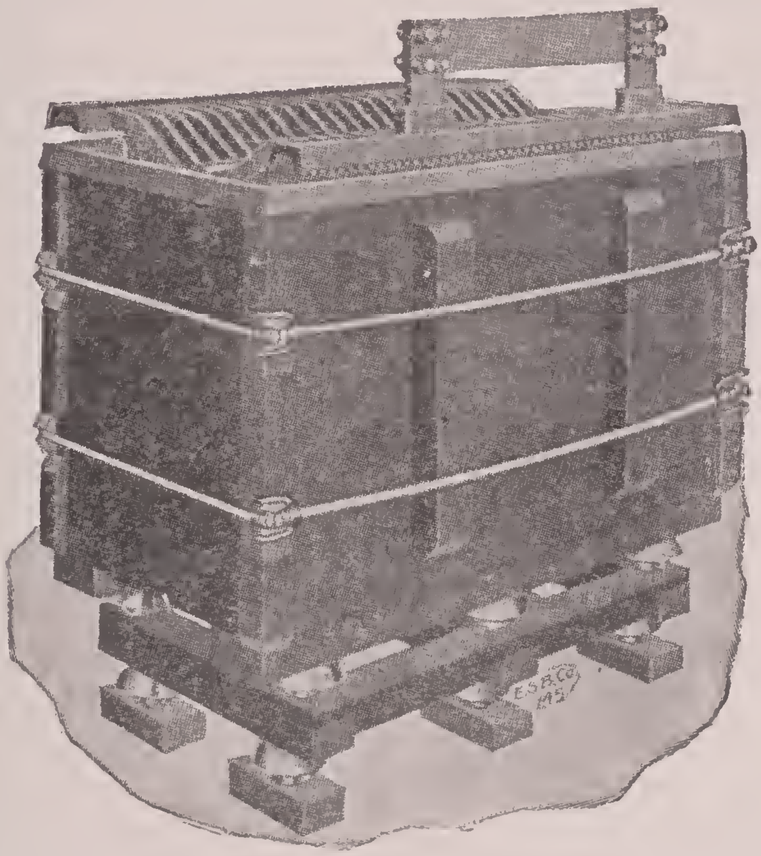

Fig 128. Storage Battery in Lead Lined Wooden Tank. Tank Rests on an Insulated Frame.

Do not habitually overcharge cells; it is a waste of money.

The cell is charged when the specific gravity of electrolyte is about 0.025 higher than when discharged.

Bubbles of gas are given off freely when cell is fully charged, because material of plate is no longer able to take up the oxygen and hydrogen which tend to be set free by the electrolysis;* these bubbles give the electrolyte the appearance of boiling, and often they are so fine that the liquid looks almost milky-white, particularly in a cell which has not been very long in use.

The color of the positive plates varies from a light brown on active parts to a chocolate color when fully charged, and to nearly black when overcharged. The negatives vary from pale to dark slate color, but they always differ in color from the positives. This indication of the amount of charge is learned by experience, but is quite definite after one becomes familiar with a particular battery.

Do not discharge too rapidly, it wastes money. A cell whose normal rate of discharge is 100 amperes for 8 hours, can be discharged at the rate of 400 amperes in one hour, but never at the rate of 400 amperes for 2 hours. You see the rapid discharge is inefficient and you only get half as much energy out of cell as you could have obtained at a slower rate.

Question 21. Do storage batteries wear out or depreciate?

Answer. Yes, it will take 10% of the cost of a battery every year to keep it in repair.

Question 22. How should a battery be put out of commission or laid up?

Answer. If, for any reason, the battery is to be but occasionally used, or the discharge is to be at a very low rate, a weekly freshening charge to full capacity at normal rate should be given. It sometimes happens that a storage battery is put out of commission for a long period. In such cases the procedure is as follows: First the battery is given a complete charge at normal rate, then the electrolyte is siphoned off into carefully cleaned carboys (as it may be used again), and as each cell is emptied it is immediately refilled with pure water. When the acid has been drawn from all cells and replaced with water, the battery is discharged until the voltage falls to or below one volt per cell at normal current; when this point has been reached the water should be drawn off. In this condition the battery may stand without further attention until it is again put into service, which is accomplished in the same manner as when the battery was originally started. If during the discharge, when the water has replaced the electrolyte, the battery shows a tendency to get hot (100 F.) colder water should be added.

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*Lesson 17.

Question 23. What troubles occur in batteries and what are their remedies?

Answer. The most serious troubles which occur in storage batteries are sulphating, buckling, disintegration, and short-circuiting of the plates. These can usually be avoided, or cured by proper treatment if they have not gone too far.

SULPHATING.—The normal chemical reaction which takes place in storage batteries is supposed to produce lead sulphate on both plates when they are discharged, their color being usually light brown and gray, due to the presence of lead oxide, on the positive plate. But under certain circumstances a whitish scale forms on the plates. Plates thus coated are said to be "sulphated." This term is, however, somewhat ambiguous, the formation of a certain portion of ordinary lead sulphate being perfectly legitimate, but the word has acquired a special significance in this connection. A plate is inactive, and practically incapable of being charged, when covered with this white sulphate, as it is a nonconductor.

The conditions under which this objectional sulphating is likely to occur are as follows:

(a) A storage battery may be left discharged for some time, even though the limits have not been exceeded.

(b) A storage battery may be overdischarged, that is, run below the limits of voltage specified, and left in that condition for several hours.

(c) The electrolyte may be too strong.

(d) The electrolyte may be too hot (above 125 F.).

(e) A short circuit may cause "sulphating" because the cell becomes discharged (on open circuit) and during charging it receives only a low charge compared with the other cells of the series. A battery may become overdischarged or remain discharged a long time on account of leakage of current due to defective insulation of the cells or circuit, or the plates may become short-circuited by particles of the active or foreign substances falling between them.

(f) By charging at a very low rate, for example, one-thirtieth of normal.

Sulphating may be removed by carefully scraping the plates. The faulty cells should then be charged at a low rate (about one-half normal) for a long period. In this way, by fully charging and only partially discharging the cells to about 1.9 volts at the 8-hour rate, for a number of times the unhealthy sulphate is gradually eliminated. When the cells are only slightly sulphated, the latter treatment is sufficient without scraping; but with cells that are very badly sulphated, the charge should be at about one-quarter the normal rate for three days.

Adding to the electrolyte a small quantity of sodium sulphate, or carbonate,* which later is immediately converted into sodium sulphate, tends to hasten the cure of sulphated plates by decomposing or dissolving the white sulphate. This is not often used, as a cell should be emptied, thoroughly washed, and fresh electrolyte added before the cell can be used again.

Sulphating not only reduces the capacity of lead storage batteries, but also uses up the active material by forming a scale which falls off or has to be removed. It also produces the following trouble:

BUCKLING, or warping of a plate, may be caused by too great expansion of the active material, which strains the ribs of the containing grid: or by uneven action on the two surfaces; for example, a patch of white sulphate on one side of a plate will prevent the action from taking place there, so that the expansion and contraction of the active material on the other side, which occurs in normal working, will cause the plate to buckle. This might be so serious that it would be impossible to straighten the plate without breaking or cracking it; but, if taken in time, it may be accomplished by placing the warped plate between boards, and subjecting it to pressure in a screw or lever press. Striking the plate is objectionable, because it cracks or loosens the active material; but, if it should be necessary to straighten a plate when no press is available, a wooden mallet may be used very carefullv, with flat boards laid under and over the plate. Buckling is caused by an excessive rate of charging or discharging, as well as by sulphating.

DISINTEGRATION.—Some of the material may become loosened or entirely separated from the plates, as a result of various causes. The chief of these is sulphating, which forms scales or blisters that are likely to fall off, thus gradually reducing the amount of active material and the capacity of the cell. Buckling also tends to disintegrate the plates. Contraction and expansion of the active material may take place in normal working, and are increased by excessive rates or limits of charging and discharging. This constitutes another cause of disintegration, particularly in plates of the Faure type, containing plugs or pellets of lead parts. The fragments which fall from the plates not only involve a loss of active material, but are also likely to extend across or gather between the plates and cause a short circuit.

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*Sal-soda; common washing soda.

The positive plates are far more susceptible to and injured by these troubles than the negatives. The former are also more expensive to make, therefore it is to them that special attention should be directed in the management of storage batteries.

SHORT-CIRCUITING may be caused by conditions previously stated, and also by the collection of sediment at the bottom of the containing well. The short-circuiting caused by the dropping in of foreign matter, or bridging by the active materials, is prevented by the use of glass, rubber, or wooden separators. The short-circuiting of plates by the formation of sediment is prevented, or the chances of it are decreased, by raising the plates so that they clear the bottom of the containing cell. In small batteries this clearance is about an inch; in large cells it is considerable, being about 6 inches, and on account of the weight of large-sized plates they are supported at the bottom by glass frames running lengthwise through the cell.

The sediment should be watched carefully, and when it reaches a depth of an inch or more at the center of the cells it should be removed. The usual method is to take out the plates, syphon the electrolyte off carefully, and then flush out the tanks until all the sediment is removed. If syphoning cannot be resorted to, a pump may be used, either of glass or of the bronze rotary type.

TROUBLES FROM ACID SPRAY.—A battery will give off occasional bubbles of the gas at almost any time; but when nearly charged the evolution becomes more rapid. These bubbles, as they break at the surface, throw minute particles of acid into the air, forming a fine spray which floats about. This spray not only corrodes the metallic connections and fittings in the battery room, but is also very irritating to the throat and lungs, causing an extremely disagreeable cough. Glass covers are sometimes placed over cells to prevent the escape of fumes, but this is not advisable as the glass becomes moist and will collect dust, thus forming a conducting surface over the battery.

Attempts have been made to do away with the spray by having an oil film over the electrolyte, but this interferes with the use of hydrometers, and sticks to the surface of the plates when they are removed, thus increasing the resistance when they are replaced. Another plan consists in spreading a layer of finely granulated cork over the surface of the liquid, but while this does not interfere with the hydrometer, it makes the cell look dirty. The general practice is to depend almost entirely upon ventilation to get rid of the acid fumes, in fact, even forced ventilation is used. A blower forces fresh air into the room, which is provided with a free exhaust. In connecting up the cells, it is advisable to use lead-covered copper cables, as this covering protects the copper, and prevents the formation of copper salts which might drop into the cell and contaminate the electrolyte.

THE PURITY OF THE ELECTROLYTE is very important, and great care should be taken to insure it. The electrolyte may have nitric acid present when "formed" (Plante) plates are used, and some chlorine, when "Chloride" negatives are used. In addition, iron may be present due to the water or acid, if the sulphuric acid is made from iron pyrites; it may also be present, owing to the corrosion of iron fittings near the cells, some of the scale falling into the electrolyte. Similarly the copper salt formed from the connections by corrosive action may fall into the cell. Mercury may also be present due to the breakage of hydrometers or thermometers. Other foreign substance might be present, but those named are the most harmful.

Nitric acid, even in exceedingly small quantities, causes disintegration, as the supporting metal grid of the plate is destroyed.

Chlorine has a similar effect.

Iron, mercury, and copper produce local action, and thus decrease the efficiency and ultimately the life of the cell.

The electrolyte should be tested about once a week for these impurities, and if any of them are present, it should be drawn off and renewed. When nitric acid is found, it is advisable to flush the cell with pure water.

Question 24. How are batteries connected to line?

Answer. Usually they are "floated" on line, meaning that the battery is always connected and charged when load is light and discharged when load is heavy. This gives the battery the least possible work to do and keeps it well charged at all times. Fig. 129 shows this. Switches are provided to cut off battery or to cut off dynamo and let battery run the lights. Usually both switches are closed as shown.

Question 25. What is end cell regulation?

Answer. If 700 volts are wanted at station 300 cells would give 750 volts when fully charged and 510 volts when at their lowest safe limit.

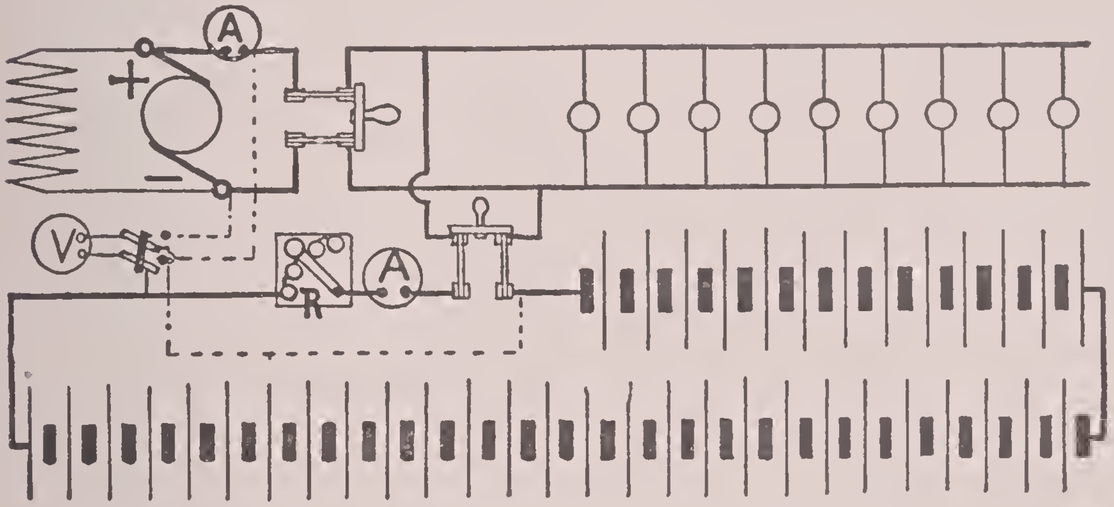

Fig. 129. Diagram of Connections for a Storage Battery to Float on Line.

If 280 cells were connected permanently and 130 extra cells arranged so as to be cut in at the end of the string of 300 cells a few at a time, then when cells were down to 1.7 volts we would have 410 in service and have full voltage.

Question 26. What is booster regulation?

Answer. A booster is a dynamo whose field magnets are excited by the current going out to the lines. Hence when the battery is being worked the hardest the booster dynamo furnishes the highest voltage which is added to that of the battery.

As the battery voltage drops the attendant regulates the field rheostat of the booster so as to add enough voltage to keep the combined voltage up to the regular voltage.

Question 27. Are batteries much used in railroad work?

Answer. Yes. Every electrically lighted train has a storage battery to run things when the train is still.

Many motor cars have storage batteries to operate the controlling devices.

Power houses have batteries to run things in case of accident.

The New York Central has five batteries, each giving 2,250 amperes for one hour and others give 3,000, 3,750 and 4,000 amperes each. The whole set can run the entire electrical division of the railroad for an hour in case of a mechanical break down.

ELECTRICALLY OPERATED TURN TABLES.

In the yards of all our large railroads the hand operated turn table has gone out of use or ought to go at once.

Locomotives are so heavy, some weighing 175 tons and a few even 200 tons, that it requires too many men to turn, especially in winter.

In busy junctions and terminals the hand turning, being so slow, is a great source of congestion and delay.

A steam "donkey" or single wheeled locomotive is occasionally used to turn the table, being attached to one end and running on the same rails as the wheels of the turn table.

The equipment consists of a small vertical boiler, a steam engine, a water tank and a coal bin. Water and coal must be brought to the table and ashes taken away.

In many places a licensed engineer is required by law. If some old locomotive engineer has the job, it is wasting a valuable man on a poor job, as his knowledge of railroading and the road should be utilized where they will be of service.

It has often been suggested that a pipe be run from the station heating plant or the shop boilers. Steam from this pipe, which should run underground to the center of the table pit, would be taken through a pivoted slip joint to the "donkey."

In this case, owing to the length of pipe, the engine would have to run on hot water most of the time.

The electric motor is just the thing to operate a turn table and they are rapidly coming into general use.

Where a terminal has been electrified the electric turn table goes without saying, but it will pay any road to install an electric turn table even if they must buy power from the local electric light company.

The same dynamos which furnished 125 or 250 volts for lighting the station or shops can operate the turn table motor.

The regular equipment would be a small railroad motor with the ordinary gearing, a rheostatic controller and a circuit breaker, the whole being mounted on a single wheeled truck. This constitutes an electrical "donkey." Such a turn table is shown in Fig. 130.

Where a large number of engines must be handled quickly, a regular turn table operator should be employed and a cab built over the "donkey" for his protection.

There are many cases, however, where it is feasible for the locomotive fireman to operate the turn table. In such a case the controller should be installed in middle of table at one side, and the cab is not essential.

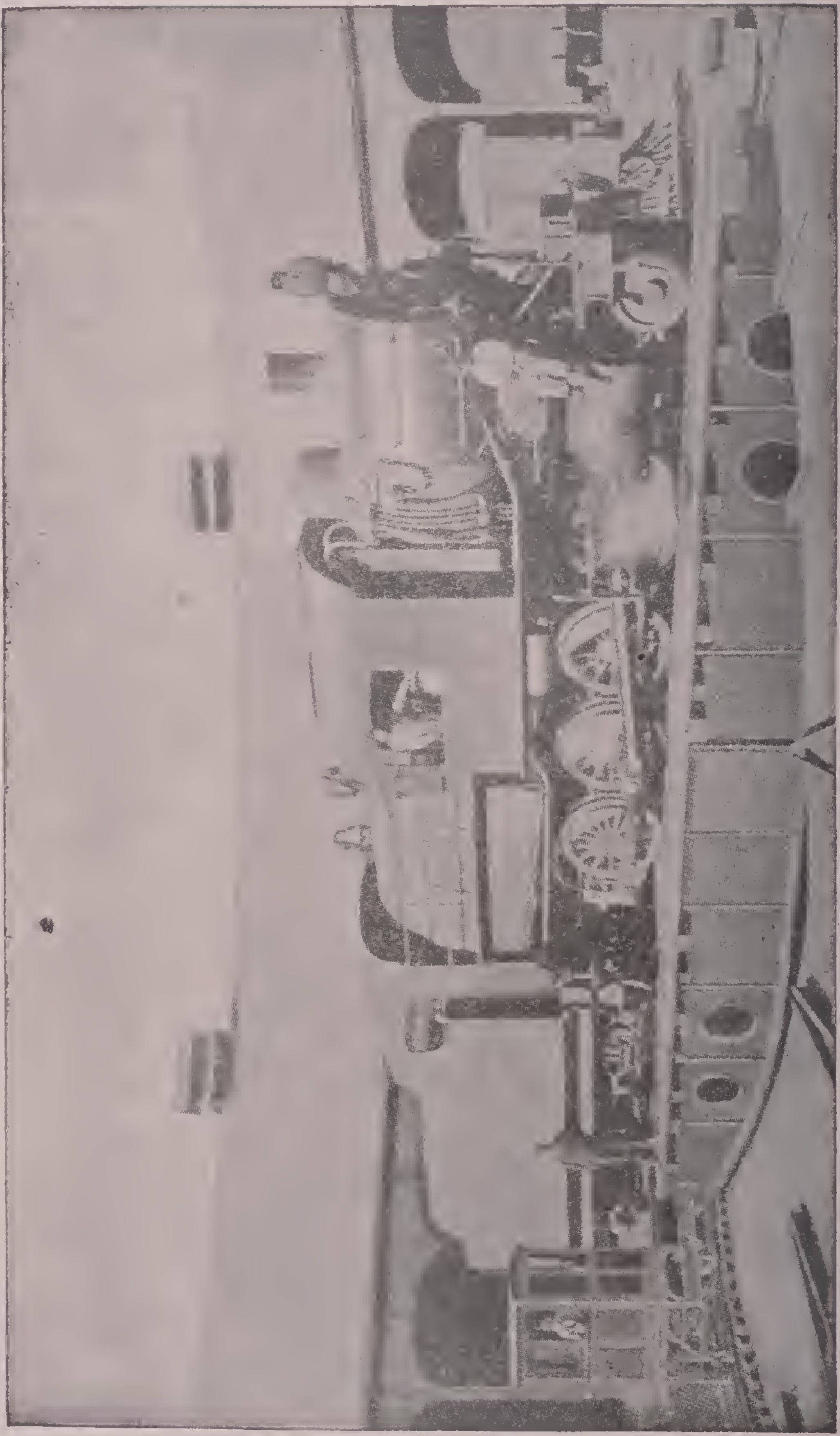

Fig. 130. Turn Table with Donkey.

The details of the "donkey" are well shown in Fig. 131, while Figs. 132, 133, 134 give all the information of the equipment that would be required. Note that the rails can be sanded in both directions.

The cost of a turn table "donkey" as in Fig. 130 is about $1,000.

Single wheel truck	$ 350
Electrical equipment	500
Installation	150
	$1,000

This is based on the assumption that the railroad buy the truck from a truck builder, do the mechanical work in their own shops and let the electricians install the electrical equipment when received from the manufacturers.

The turn table shown in Fig. 135 is of the "draw bridge" type. The table rests on a heavy cradle which turns on a train of small wheels.

A large stationary gear as shown is engaged by the pinion of the vertical motor shaft.

You will notice that a "donkey" drives by friction like a locomotive so that ice on rails, or oil will reduce traction and make sand necessary. The "draw bridge" type drives positively by a gear.

Whatever type is used the ordinary street railway motor is best adapted to the purpose. It is completely enclosed and water and dust proof.

The conditions of frequent starting and large momentary overloads makes the direct current series motor the best. If only alternating current is obtainable the compensated series motor will give good service. If only

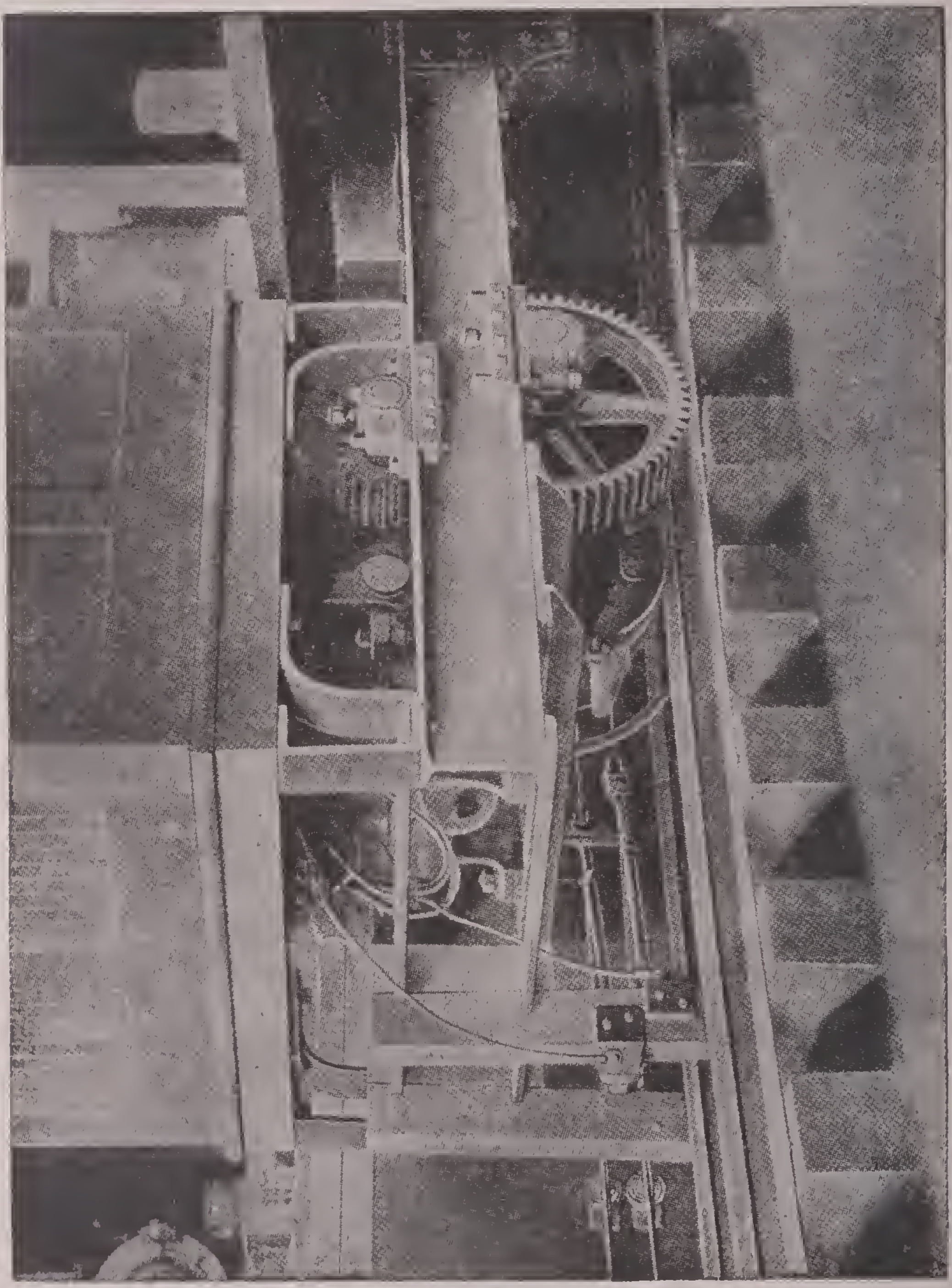

Fig. 131. Under Part of Donkey.

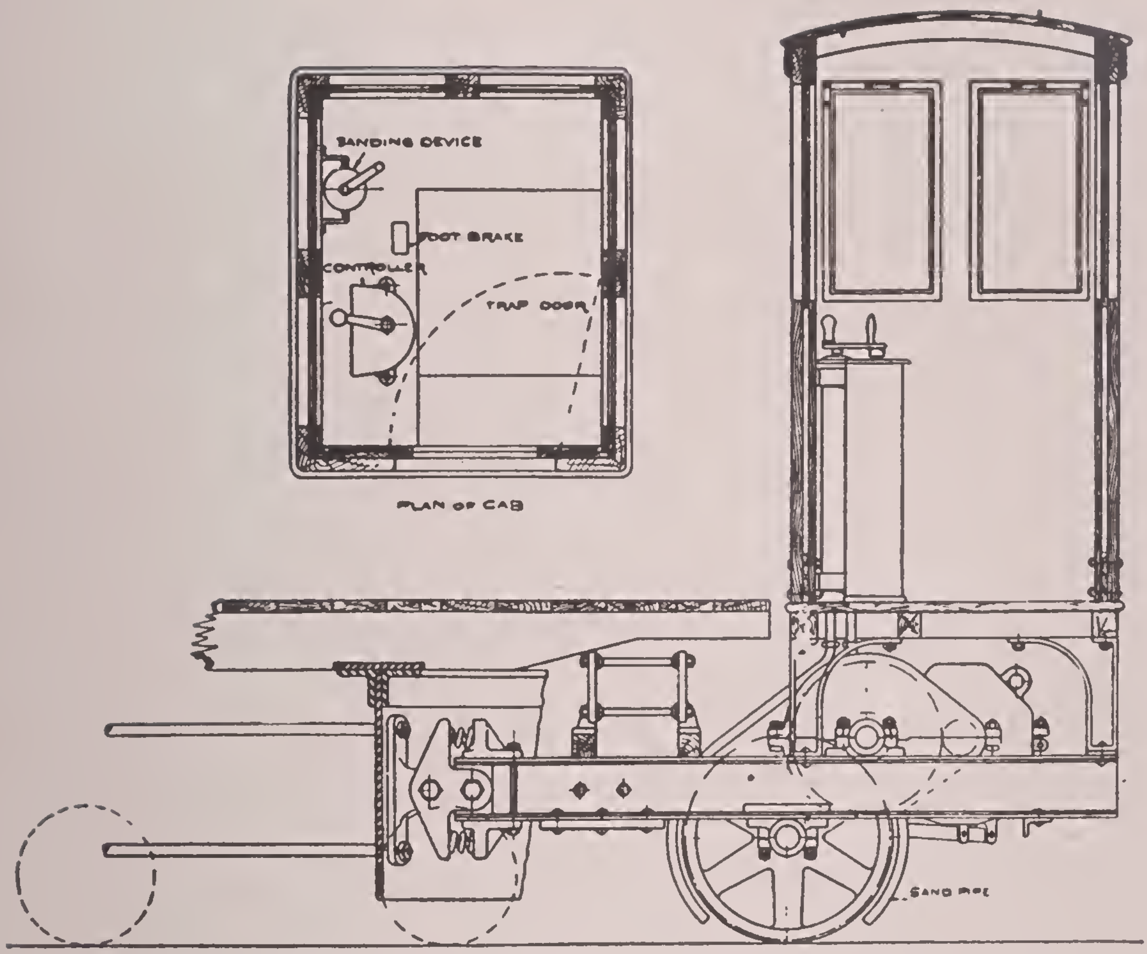

Fig. 132. Side View of Donkey and Plan of Interior of Cab.

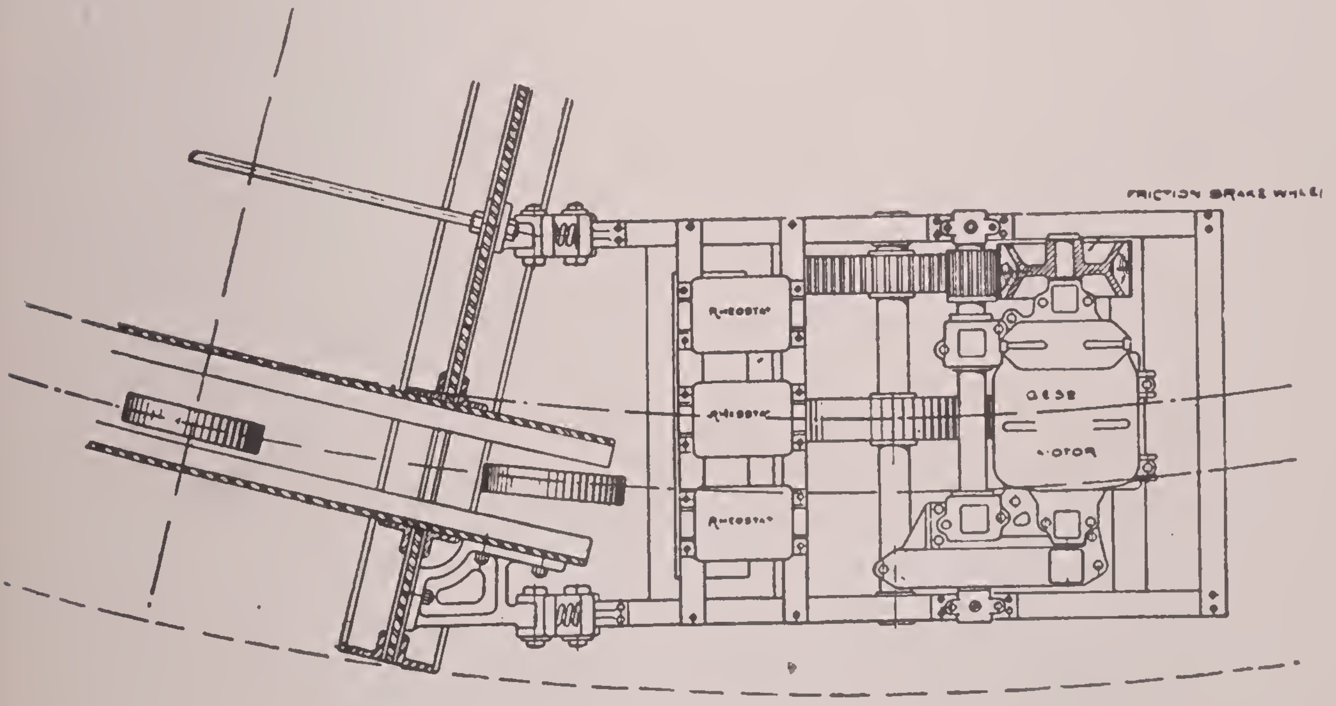

Fig. 133. Plan of Under Part of Donkey.

multiphase alternating current can be obtained an induction motor will do the work better than hand or steam. The induction motor should be of the definite wound armature, collector ring, external resistance type, and be designed for speed variation. (See Lesson 27.)

In any case the motor must be designed and constructed to stand rough use and even positive abuse.

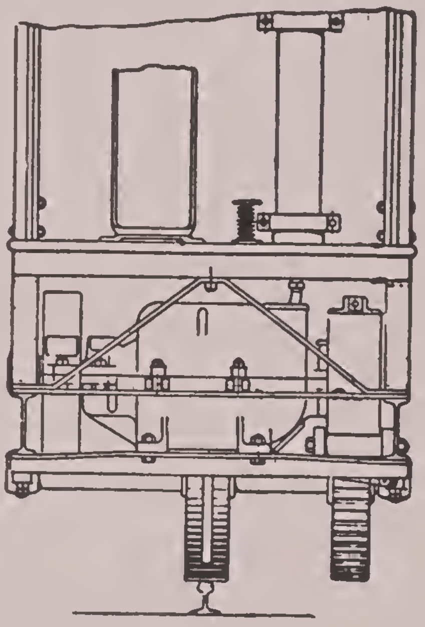

Fig. 134. End View of Under Part of Donkey, Gear Wheel of Motor on Right, Single Drive Wheel in Center.

The motor is usually provided with feet, and in place of the car axle an intermediate shaft is substituted so that there is a double reduction gearing. Both sets of gears run in a gear case filled with oil or soft grease.

The armature shaft of motor is extended at the end opposite the pinion and a hand brake fitted. Sometimes this is set by a wheel and sometimes by a weight or a spring and is released by a foot lever.

The controller is like a street car controller except that it has no separate reverse wrench.

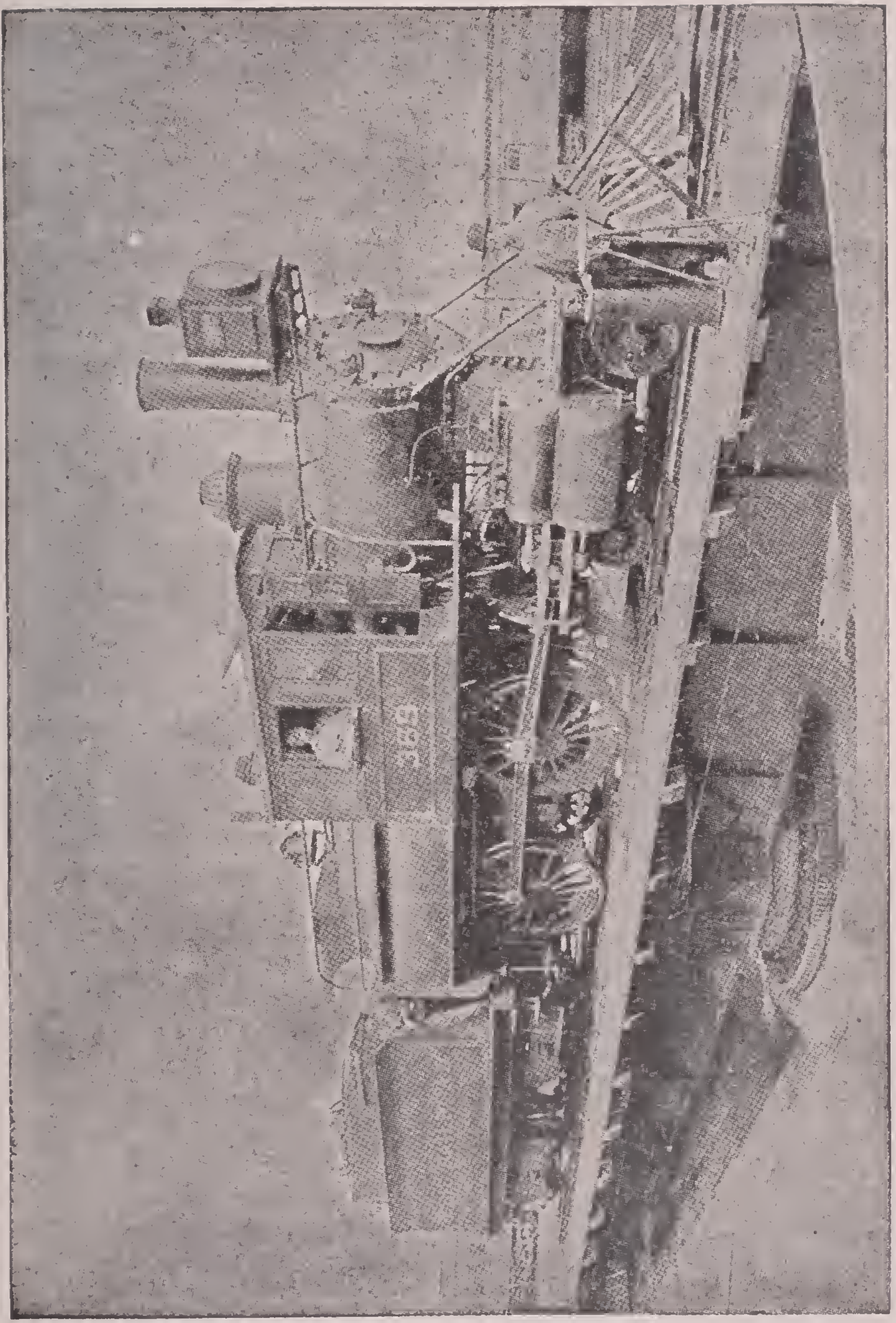

Fig. 135. Draw Bridge Type of Turn Table.

The handle being in center, power is off; moving it to right turns table to right, to the left turns table to left.

The resistances are like those on a street car.

The circuit breaker serves as a switch and protects from serious overloads.

The advantages of electrically operated tables are: Low cost of maintenance and operation; speeds up, moves and stops quickly; perfect control of speed; consumes power only when work is done.

Perhaps time saving is its greatest advantage. In a certain terminal the new round house was built to accommodate twice as many locomotives as the old one. The electrical turn table served this round house with less delays than the hand table caused when serving the old house.

The actual power to turn a 60-foot table with a 100-ton engine on, is from 8 to 12 H. P. The speed of operation was one turn in 40 seconds. At the moment of starting the power ran up to about 20 H. P.

It is for this reason that a 20 H. P. railway motor is installed.

A 10 H. P. motor of regular type would operate the table, but not as well. The reason is not because the 20 H. P. railway is more powerful than a 10 H. P. regular motor, for strange to say they are of about equal power. (See Lesson 27.)

The railway motor is best suited to the work and should be installed.

No time should be wasted in trying to balance engines on the table; in fact, the 8 H. P. result was obtained with engine slightly out of balance; 9 H. P. was when engine was balanced and 12 H. P. when much out of balance.

In one yard where the electric table turned 300 locomotives a day, the cost of the power used was less than the cost of hauling the coal to the steam donkey previously employed. It would have been utterly foolish to waste time in balancing engines to try to save a little power.*

In this yard the actual cost of turning a locomotive by electric power from their own shop, was 1.4 cents. This was obtained by averaging the total expense for six months' use of the table. Had this power been purchased from the local electric light company, it would have cost them 1.9 cents per locomotive.

There are three good ways of bringing the power into the turn table:

The best way is to lead the wires from underground up to a pair of cast iron rings and have brushes in the table to collect the current.

When center pivots are solid and the under bracing complicated this cannot be done.

For a turn table of this description the method shown in Fig. 131 is good.

Two trolley wires, in spans of 6 or 8 feet, are placed around the wall of the pit, supported by trolley hangers of the "toggle" type, ordinarily used in electric mine haulage. Short trolley poles are flexibly attached to the "donkey," so as to allow a horizontal movement on account of the variation in the trolley wires and a vertical movement to accommodate the tilting of the table. This scheme is simple and inexpensive, and in practice has operated in a very satisfactory manner.

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*While extravagance is to be deplored, false economy is equally foolish, spending a dollar to save 93 cents is not business nor religion. Railroad officials are not the only ones gone crazy on "economy" or "efficiency." I shall refer to this at other places.

In some places, on account of the possibility of the pit being flooded, neither of the arrangements described above is practicable and it becomes necessary to collect the current from above the turn table. A very ingenious arrangement for this purpose has been used on a turn

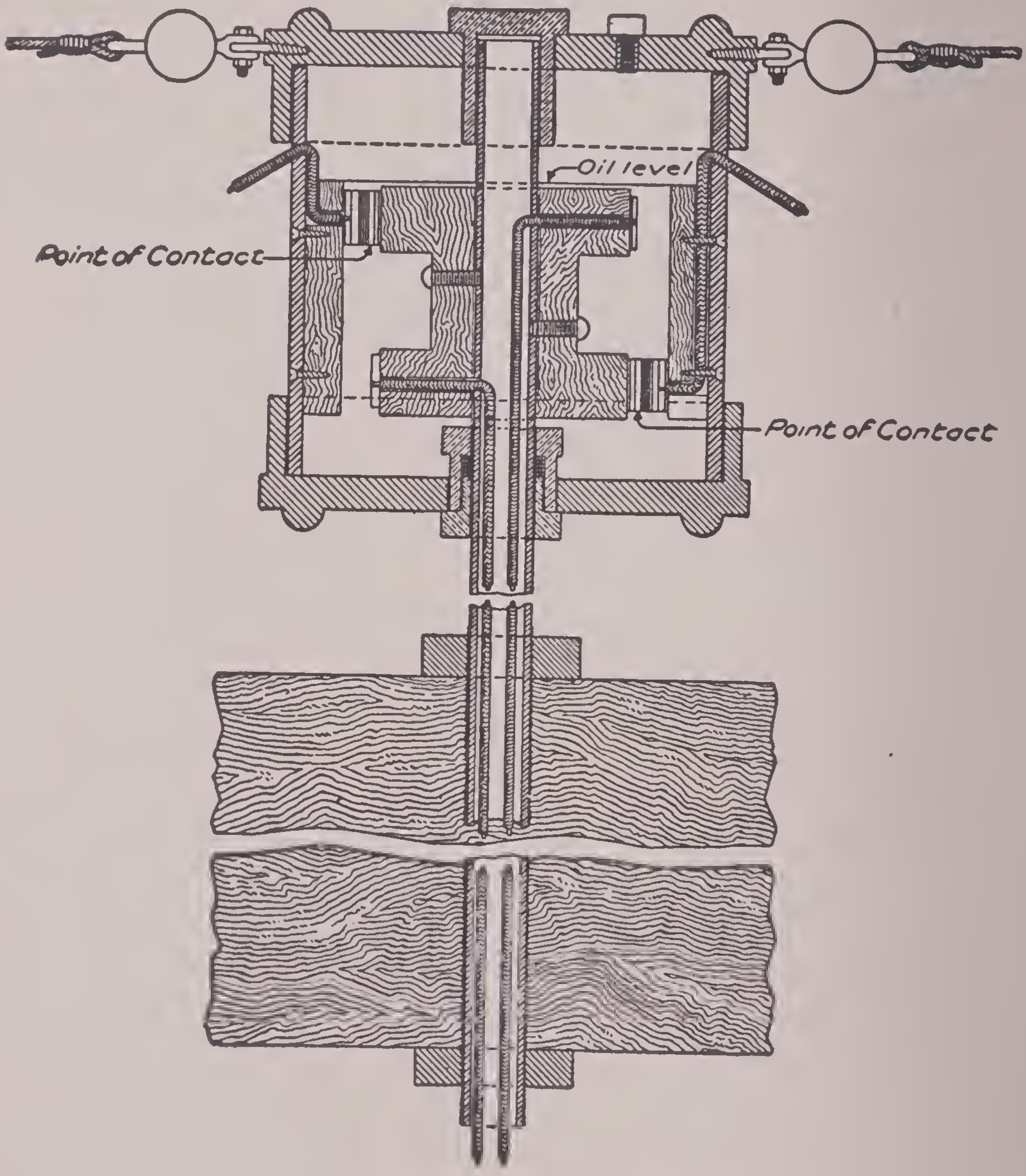

Fig. 136. Overhead Contact for Turn Table.

table where the pit occasionally fills with sea water. A light arch was built over the center of table to support directly over pivoted point the device shown in Fig. 136. The case is a piece of 8-inch steam pipe with a regular cap fitting screwed on each end. A bearing is set in at the top and a stuffing box at the bottom.

The case is held stationary by wire rope guys attached to regular trolley road insulators and the two electric wires enter the case and end in copper brushes insulated by a hard wood shell.

A piece of 1-inch gas pipe turned smooth on the outside at one end is fastened to the table. Its upper end revolves in the bearing of the case and takes most of the weight of it. The guys merely steady it and prevent rotation. The gas pipe revolves in the oil tight stuffing box at bottom of case. A hard wood spool on the gas pipe carries two copper rings which collect current and from which the two wires run down inside the pipe to the turn table.

The case is filled with oil which serves a triple purpose: it lubricates, insulates, and prevents the gases and steam from the locomotive from running contacts and insulation.

LESSON 17.

ELECTROLYSIS.

The word electrolysis means a loosening up by electricity done in a liquid.

There are three classes of liquids:

(1) Do not conduct electricity, as oils, petroleum products.

(2) Simply conduct like mercury, melted metals.

(3) Conduct and are loosened up so that the different constituents separate and the constituents of the same kind collect together.

Dilute acids (1 part acid and 20 parts water); solutions of metallic salts (copper sulphate, ammonium chloride); melted chemicals; are in the third class.

Liquids of the third class are called Electrolytes and the process Electrolysis.

Now when an electric current is passed through these solutions, they split up into parts, one part being liberated at the point where the current enters, and the other part where it leaves the liquid. If, for instance, we pass a current through water, we find oxygen gas being liberated where the current enters the water, and hydrogen gas where it leaves. The conductors that lead the current into and out of the liquid have been called the electrodes (or electricity doors). The leading-in electrode is called the anode (or entering door), and the leading-out one the cathode (or exit). Therefore we say oxygen is liberated at the anode, and hydrogen at the cathode. If the solution contains a metal it is always liberated at the cathode.

The plus wire of circuit is attached to anode and negative wire to the cathode.

When a metal is dissolved in a dilute acid and the water boiled away the solid substance left is called a salt.

If the metal sodium is dissolved in weak muriatic acid and the water boiled away common table salt is left behind. If this is dissolved in water again we can by electrolysis separate it into the soda and muriatic acid again.

Cryolite is a compound with a great deal of aluminum in it. By melting it and while liquid passing current through it the aluminum is collected at the cathode.

The pieces of the electrolyte produced by electrolysis are called ions.

HOW ELECTROLYSIS TAKES PLACE.

Electricity is an invisible something known only by its effects. It can be moved from place to place through the air as Marconi has shown, or it can be more accurately and more cheaply transferred by copper wires. How the air or the copper wire conducts the electricity we do not know.

When electricity is transferred through a liquid we know that certain kinds of little particles of the substances in the liquid carry the electricity across from the anode to the cathode and stay there and certain other kinds of particles collect about the anode, for there is a transfer of electricity in both directions.

Unless these little particles are present the liquid will not conduct. If they are present the liquid conducts and while conducting the loosening process goes on and more particles (ions) are produced to keep up the conductivity of the liquid.

ELECTROLYSIS OF WATER.

Take a glass of boiled and filtered water (it would be better if it were distilled water). Bring the + and — wires from a 3-cell battery to the glass and fasten strips of platinum foil to the ends by wrapping on wires. Bend the wires up and over the edge of glass and let platinum strips hang in water. Do not let the copper wires get even wet, much less in the water. An ammeter would show no current passing because the pure water has no ions in it. Now pour in a teaspoonful of sulphuric acid and the water begins to conduct (due to presence of ions) and electrolysis commences.

The water is composed of hydrogen and oxygen in the proportion of 2 to 1, and the electrolysis allows these gases to escape into the air so that after a while all the water will be turned to gas.

To a railroad man electro plating and destruction of water and gas pipes are the two important things.

ELECTRO PLATING.

Electro-plating and chemical-plating are often mixed up in people's minds.

If you thrust a pen knife blade or a key into the copper sulphate solution used in a gravity cell, the knife is instantly copper plated by chemical action. If a sheet of iron, sprinkled with sal ammoniac is dipped in a bath of melted zinc it is chemically plated and is called galvanized iron. Electricity had nothing to do with either of these platings.

As we know that the metals are dissolved into the solution at the anode and deposited at the cathode, we may electroplate an article with copper in the following way:

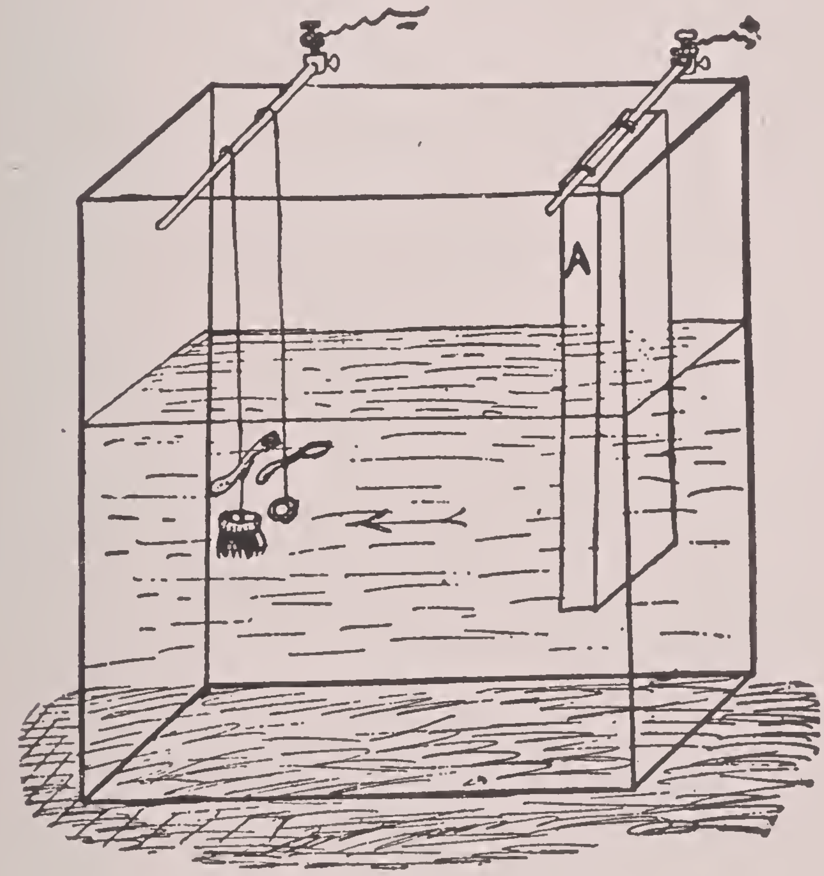

Fig. 137. Electro-plating Cell.

Make a bath of 1 gallon water, 10 oz. potassium cyanide (deadly poison), 5 oz. of copper carbonate, and 2 oz. potassium carbonate.

Place in a glass or wooden tub, connect to positive wire a slab of copper (Fig. 137), and to negative wire the thoroughly cleaned articles. The passage of a current of low voltage will plate copper on the articles.

Brass may be electro-plated on iron castings. This is a cheap and nasty substitute for a solid brass casting.

Impure ores of copper, scrap copper, old telegraph and electric light wires in which there is always more or less solder, and copper mixed with other impurities, may be purified by electrolysis, the cathode being a plate of pure copper, the bath a solution of sulphate of copper, and the anode the impure metal. The pure copper replaces the exhaust from the bath, and the impurities fall to the bottom of the tank. Recovered copper thus deposited is extremely free from impurities, and is used for electrical conductors where low resistance is required.

ELECTROLYTIC CORROSION.

When the current has passed through motors it returns to the power house by many paths, some of which are: Rails of the track, return feeders between rails, elevated railway structures, waterpipes, gaspipes, cables of telephone wires, Edison tubes, adjacent streams of water.

Let us consider the water and gaspipes and the cables. The current going into these is positive and when finally the current leaves them to go to the earth plates of the power house, if the ground is the least bit moist, metal is dissolved and taken away. In this way holes have been eaten in gas and water mains, and the sheathing of cables destroyed. The return current has a habit of leaving the pipes at each joint and coming back into pipe on the other side. This causes corrosion at every joint.

This electrolytic corrosion is frequently the cause of law suits against the railroad companies.

To reduce the evil and to be able to show in case of suit that every possible precaution has been taken the company should:

Thoroughly bond the track rails at every joint.

Run a bare copper wire along between the rails and connect each rail of the track to it.

Whenever a pipe or cable is found to be in danger of corrosion, run a wire from negative pole of station to the pipe and make a well soldered connection.

It is evident that alternating current will not cause corrosion for it is rapidly reversing in direction.

Main line tracks will have far less trouble with corrosion than branches, and city extensions, belt lines, etc., which run through streets crowded with pipes and cables.

CIRCUITS.

An electric current is so called because it is the thing through which the electricity passes or makes its circuit around through the different pieces of apparatus and machinery.

The word circuit is used in connection with many other words as: series circuit, parallel circuit, short circuit, A. C. circuit, etc. These will all be explained in the following lessons.

A dead circuit must be made live before it can deliver power, and where so delivering it is called a loaded circuit.

Every loaded circuit has Conductance, Resistance, Insulation, Pressure and Current which are explained in the following lessons.

The habit of referring to circuits as lines has grown so that the words are almost interchangeable.

We ought to be more accurate and use the words in this manner.

When a wire starts from the power house and returns again we have a circuit. When we speak of a part of this circuit we say "the line between Chicago and Hinsdale."

When the wires run from a power house to a sub-station we may call it "the line." Of course there is an electric circuit there but we are always thinking of it as if current only flowed from power house to sub-station, and speak accordingly.

When one side of the circuit is composed of rails, earth, etc., we always speak of the copper part as the "line" and the rest of it as the "ground."

Fig. 138 shows several kinds of circuits and corresponding effects.

Taking the top part of the figure with the solid lines. Starting from the terminal of the battery we have a series circuit through the magnet, lamp, resistance, electrolytic tank and back to the terminal of the battery.

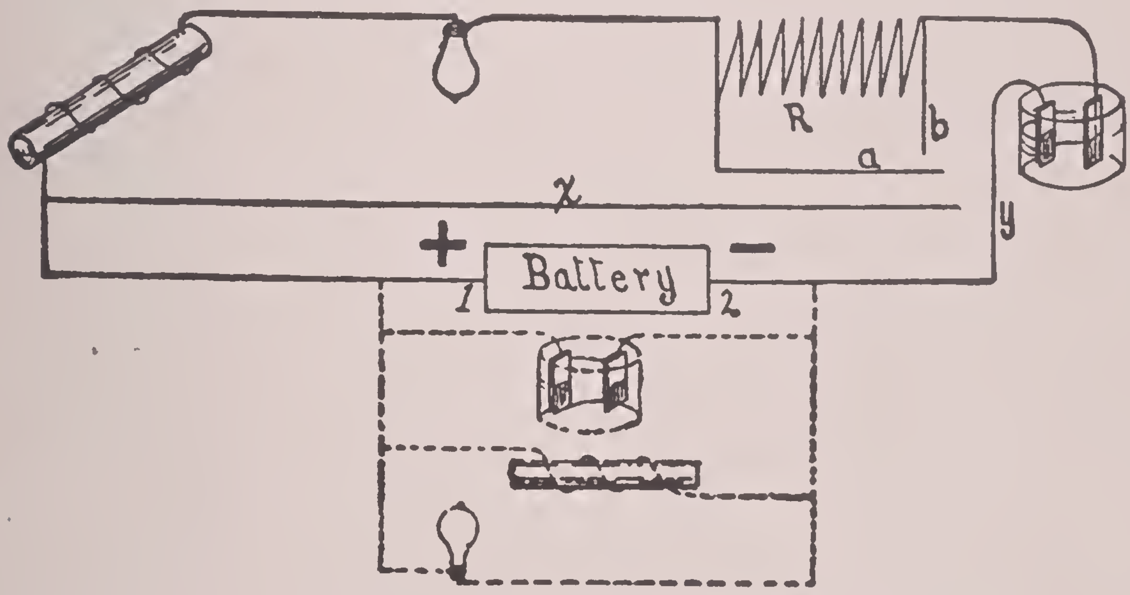

Fig. 138. Diagram of Circuits.

In such a series circuit the same current must pass through each of the pieces of apparatus. If the circuit had all lamps, or all electro-plating tanks this would perhaps be satisfactory, but since a lamp takes one-half to one ampere and the plating bath 10 amperes and upwards, it is evident that such a circuit will not work at all when different kinds of apparatus are in it. Either the plating bath won't work or the lamp will be burnt out in a few minutes.

Another objection to a series circuit is that should we wish to stop the flow of current through the resistance R, we cannot open the circuit by a switch as that would cut the current off from all the rest of the apparatus. A short-circuiting switch must be installed as shown at a, b. When the ends of these wires are connected by a switch, a shunt circuit is formed around R and the shunt will carry the current when R is removed. The shunt circuit must be made of large enough wire to carry the current formerly carried by R without over heating.

Such a short circuit of a part of a series circuit causes no trouble at all but a short circuit of the whole of a series circuit must be made more carefully. The resistance of the wires x, and y forming the short circuit should be very low when a series dynamo is used and very high when a battery is used.

A very low resistance short circuit on a series dynamo stops the generation of current, and a very high resistance short circuit on a battery stops it generating current.

A high resistance short circuit is always referred to as a shunt, and the words short circuit reserved for low resistance ones.

Looking at the dotted part in Fig. 138 we have two, mains running from the battery and branches running across between mains; the branches containing the apparatus.

The mains and branches form parallel circuits and the apparatus is said to be installed in parallel or multiple.

Several distinct advantages are gained by the parallel system.

Each piece of apparatus can draw as much current as it needs without interfering with other apparatus.

The current may be cut off from any of them by opening a switch in its branch without affecting the remaining branches.

Short circuits (i. e. low resistance) anywhere in a parallel circuit will cause considerable damage.

Parallel circuits are fed by shunt dynamos or alternators. A short circuit on a shunt dynamo causes it to generate an enormous current and may destroy the apparatus short circuited and the dynamo's armature. Alternators do not produce such large currents when short circuited so in this case it is the apparatus short circuited that suffers most.

When each branch of a parallel circuit contains several pieces of apparatus in series, the whole is called a series parallel circuit.

Suppose we now learn how electricity flows through circuits.

In hydraulic, pneumatic or steam engineering, the indications of the pressure gauge are of the utmost importance to the engineer; in fact, he is always considering and asking about the pressure, and does not trouble himself about the water, air, or steam, for none of these would be of any use to him unless they existed under a certain head or pressure. It is simply the pressure under which they exist that gives to them their working power.

In a similar way the electrical engineer is always concerned about the electrical pressure; he does not talk or think much about the electricity, but the electrical pressure is always in his mind as being of the first importance.

The hydraulic engineer measures his pressure in pounds per square inch, that is to say, his unit of pressure is that exerted by a pound weight. The electrical engineer's unit of pressure is called the volt (from Volta, an Italian electrician), the consideration of which we will leave for a future lesson. It is owing to this pressure that a current of electricity flows around a conducting circuit. No current could possibly flow unless there was a difference of electrical pressure in the circuit, in the same way that no water would possibly flow through a water conductor unless there existed a difference of pressure.

Instead of calling it the electrical pressure, we might call it the electricity-moving force, or the electro-motive force, or, for brevity, the E. M. F., which is the term most commonly applied to the electrical pressure; thus we speak of the E. M. F. of a circuit as being equal to so many volts.

It would perhaps be well to point out here the engineer's meaning of pressure.*

We may exert a pressure and still have no resultant motion; as, for example, suppose a man applies a pressure (a moving force) at one end of a table, which would of itself be able to move the table along the floor; if now a boy pushes at the opposite end and in the opposite direction, it is certain that the table would not be moved as rapidly as before, providing the man pushes with the same force throughout, while if another man takes the place of the boy and pushes with equal force to the man opposite to him, the table would not be moved at all, although there is now a greater pressure being applied to the table than in the original case. It will therefore be seen that the result obtained does not depend on the pressure, but on the difference of pressure, and in all cases where pressure is spoken of it is the difference of pressure that is meant.

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*This illustration is taken from Mr. Tyson Sewall.

Returning to the experiment with the table, we have just seen that before the table can be moved we must provide a table-moving force, but when this is provided it does not follow that the table will move even then—it all depends on the resistance offered. We can imagine a very heavy table, with rough feet, standing on two rough boards, and the man applying a moving force to it but producing no movement; whereas when the floor has been smoothly planed he may be able to move it slowly, and by fitting wheels or casters to the feet of the table he may be able to move it rapidly with the same moving force.

We see that the rate of movement of the table depends partly upon the table-moving force applied and also in part upon the resistance offered by the boards on which the table stands. It is directly proportional to the former and inversely proportional to the latter. That is to say, if we double the moving force while the resistance remains the same, the rate of movement of the table will be doubled, and if we keep the moving force the same and halve the resistance, the rate of movement of the table will be doubled. This could be stated thus:

$$\left.\begin{matrix}\text{Rate of move-}\\ \text{ment of table}\end{matrix}\right\}\text{ is proportional to }\frac{\textit{table-moving force}}{\text{resistance.}}$$

Therefore the rate of movement of the table is a thing entirely dependent on two other things, and in trying to find its value we have to ask, first, what is the moving force available? and second, what is the resistance offered? The same applies to water moving in pipes and this is perhaps a better analogy to the electrical case. We say there is a current of water flowing through the pipes, but this current is flowing simply because there is a difference of pressure between the two ends of the pipes, and as the pipes offer a certain resistance, while these two things remain constant, the strength of the current will remain constant also. If we desire to alter the rate of flow (the current), we must alter either the water-moving force (the head) or the resistance (the tap). We can now see why the engineer is not concerned so much about the current; he may want a certain current to flow, but he gets it by seeing either to the water-moving force, or to the resistances, or to both.

If we now apply this electricity we find the same ideas in the mind of the electrical engineer. If he desires a certain current he asks himself, "What E. M. F. (electro-motive force) have I available?" and then, "What resistance must I have in the circuit?" and he makes all alterations in the current strength by adjusting the one or the other, or both, to suit. If the circuit has a fixed resistance then he cannot alter the current flowing round it except by proportionally altering the E. M. F., that is to say, if he wishes to have twice the current strength he must put twice the E. M. F. into the circuit. If the E. M. F. has a fixed value, then he cannot alter the current without altering the resistance of the circuit, thus—if he wishes to double the current strength he must halve the total resistance of the circuit.

All the so-called generators of electricity, dynamos, batteries, etc., are simply devices for producing and maintaining an E. M. F. Some dynamos produce high E. M. F.'s from 2000 to 10000 volts and even higher, while battery cells produce low E. M. F.'s from 1 to 2 volts only.

To make the analogy between the water system and the electrical system more correct, we should suppose a closed circuit of pipes, as shown in Fig. 139, completely filled with water, having a rotary pump P in the circuit, and furnished with a tap R a pressure gauge PG, and a current gauge C G.

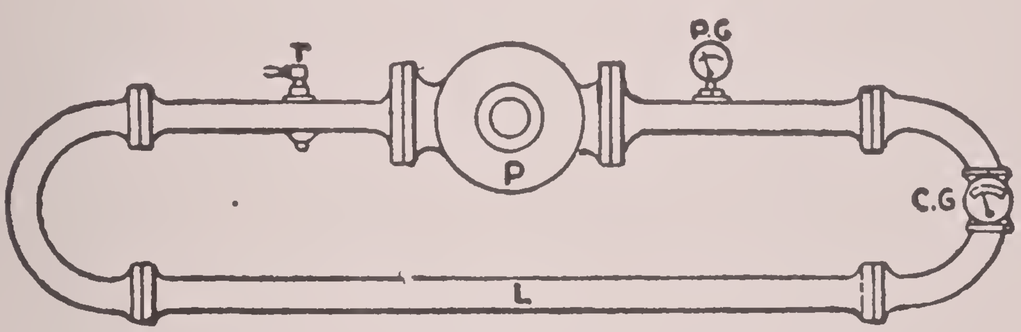

Fig. 139. Simple Hydraulic Circuit with Gauges.

Suppose now we turn on tap T and start the pump working, the pressure gauge will indicate a difference of pressure in the circuit, and the current gauge will indicate a current, flowing round the circuit.

In this case we are not generating water, we are simply putting into motion the water that was already there, and this is done by creating a difference of pressure by means of the pump, and by providing a conducting circuit. If we stop the pump, the two indicators will point again to zero, but there is just the same amount of water there as we started with, there has been no consumption of water.

In the same way we have to think of an electrical circuit (Fig. 140). The dynamo D is simply a device for producing a difference of electrical pressure, and is put into the circuit to act exactly as the pump does in Fig. 139 if we switch on S, which is comparable with turning on the tap in Fig. 139, and start the dynamo working, the pressure gauge (called the voltmeter) VM will indicate a difference of electrical pressure or an E. M. F., and the current gauge (called an ampere-meter, or for brevity an ammeter) will indicate a current flowing round the circuit. In this case we are not generating electricity, but simply putting into motion electricity that was already there.

Going back to Fig. 139, suppose we turn off the tap T and keep the pump working, then the current meter will indicate no current, but the pressure gauge will indicate a slightly higher pressure than before. Here we have a water-moving force, but the resistance in the circuit is now exceedingly great, consequently no current can flow.

Similarly in Fig. 140 if we switch off, still keeping the dynamo running, the voltmeter will show a slightly higher pressure, while the ammeter will indicate no current. Here again we have the one essential for a flow of electricity round the circuit, but not the other, for in switching off we have introduced into the circuit an enormous resistance.

It will be noticed that we have referred throughout to the current as being not the movement of the table, or the flow of water or electricity, nor yet the quantity of water or electricity moved, but as the rate of movement. Fifty gallons of water is not a current of water, but 50 gallons per minute is a statement of the rate of flow, and consequently is a statement of the current strength. A current is the rate of flow.

Let us return again to our water circuit (Fig. 139) and examine it more closely. Imagine the system to be quite full of water, and remember that water is a practically incompressible fluid. If now we have our pump at work with the tap turned off, we shall have a difference of pressure between the two sides of the pump but no current. The moment we turn the tap on the current will flow, but this current will be everywhere in the circuit of the same strength, it will not be strongest at the pump and get weaker as we go round the circuit, but will instantly have the same strength everywhere, and the current does not get used up in going round the circuit.

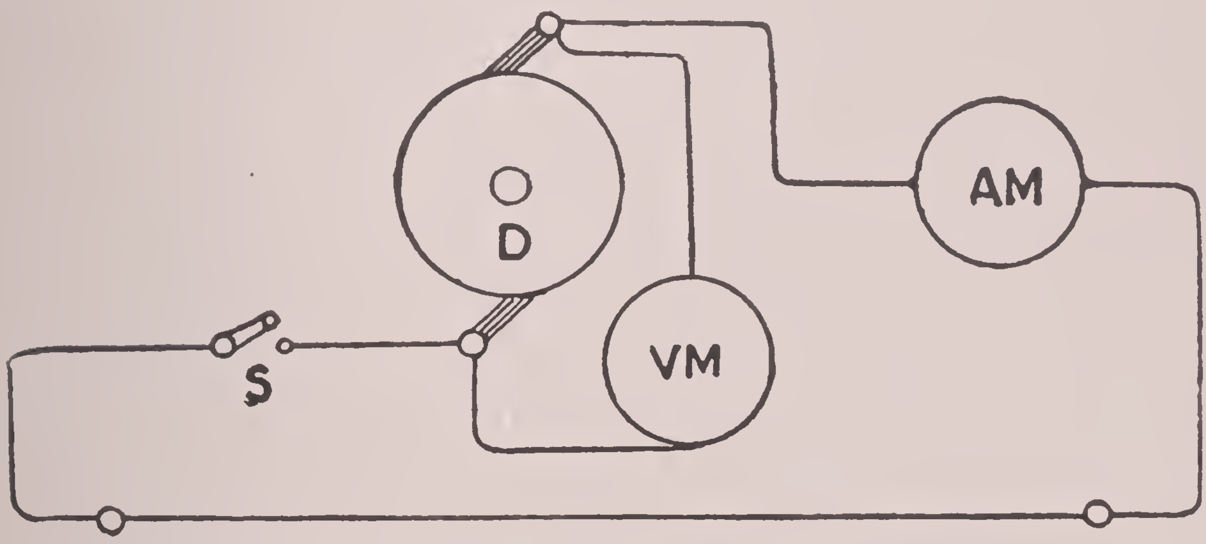

Fig. 140. A Simple Series Circuit, with Instruments.

This is exactly the case with the current in Fig. 140. If the dynamo be at work we have an E. M. F. in the circuit, but while the switch is off no current can flow. The moment we switch on there is a current in the circuit which is everywhere of the same strength, not stronger near the dynamo, and getting used up as it goes round the circuit, but of the same strength everywhere in the circuit.

It is evident that flow of current is regulated by pressure and resistance of circuit so that

$$\text{Current} = \frac{\text{Resistance}}{\text{Pressure}}$$

using the principles taught in Formulas Page 210 we get two other forms of this rule

$\text{Pressure} = \text{Current} \times \text{Resistance}$

$$\text{Resistance} = \frac{\text{Pressure}}{\text{Current}}$$

A man named Ohm first noticed this rule and it is called Ohm's Law in his honor.

Let us now consider a few problems on the Ohm's Law.

1. The E. M. F. in a simple circuit (Fig. 140) is 100 volts, the resistance of the whole circuit is 50 Ohms. What current will flow through the circuit?

Ohm's law says, $\text{current} = \frac{\text{E. M. F.}}{\text{Resistance}}$

Therefore in this case $C = \frac{100}{50} = 2$ amperes.

It must be fully realized by the student that while the E. M. F. remains at 100 volts, and the resistance remains at 50 ohms, the current in that circuit will be 2 amperes, no more and no less. It is impossible for any other strength current to flow.

2. The resistance of the circuit being reduced to 10 ohms, while the E. M. F. is kept at 100 volts, what is now the strength of the current?

$$\text{Again current} = \frac{\text{E. M. F.}}{\text{Resistance}}$$

$$\text{Therefore } C = \frac{100}{10} = 10 \text{ amperes.}$$

3. It is found that when an E. M. F. of 100 volts is applied to a circuit, a current of 25 amperes flows. What is the total resistance of the circuit?

$$\text{Resistance} = \frac{\text{E. M. F.}}{\text{current}}$$

$$\text{Therefore resistance} = \frac{100 \text{ volts}}{25 \text{ amperes}} = 4 \text{ ohms.}$$

4. In the same circuit we find that by twisting upon itself some of the wire of which it is composed, the current increased to 50 amperes. What is now the resistance of the circuit, and how much resistance has been cut out by so twisting up the wire?

Again by Ohm's law—

$$\text{Resistance} = \frac{\text{E. M. F.}}{\text{current}}$$

$$\text{Therefore resistance} = \frac{100}{50} = 2 \text{ ohms.}$$

It had four ohms previously; we have therefore cut out $4 - 2 = 2$ ohms.

5. In a circuit of 20 ohms resistance, a current of 5 amperes is flowing. What is the E. M. F. in the circuit?

By Ohm's law—

The E. M. F. = Current × Resistance.

Therefore E. M. F. $= 5 \times 20 = 100$ volts.

6. What is the E. M. F. in a circuit whose resistance is equal to 10 ohms when a current of 20 amperes flows through it?

E. M. F. = Current × Resistance.

E. M. F. $= 20 \times 10 = 200$ volts.

We have now to consider circuits other than the simple circuits just described, known as divided circuits or parallel circuits.

Fig. 141 represents a simple circuit in which the principal resistance consists of a conductor A of 50 ohms resistance; the remainder of the circuit consists of a dynamo capable of generating the E. M. F. of 100 volts, and thick connecting wires joining it to the ends of A.

If we neglect for the present the small resistances of the dynamo and connecting wires, then the current flowing is

$$C = \frac{E}{R} = \frac{100}{50} = 2 \text{ amperes.}$$

Suppose we now join the points C and D with another conductor B exactly similar to A, as in Fig. 142. Will the current through the dynamo be greater or less than before? And will it make any difference to the current flowing through A?

Let us see. The circuit B having the same resistance as circuit A conducts just as well, hence twice as much current can flow between C and D, as flowed before. It is evident that the resistance offered is now half what it was. In Fig. 141 it was 50 ohms, in Fig. 142 it must be 25 ohms, by Ohm's law the current through the dynamo has doubled, for $C=\frac{E}{R}=\frac{100}{25}=4$ amperes; 2 amperes through A, and 2 amperes through B.

To make this quite clear, let us take our water analogy again. Fig. 143 represents a water circuit similar to our last electrical circuit. If the pump be working continuously, maintaining a difference of pressure between its ends, then with *T* turned on and *t* turned off, we should have a flow of water round the circuit through A, which would offer the principal resistance of the circuit, and the current gauge would indicate a certain current flowing through the pump. If now we turn on tap *t*, we open up another path for the water to flow in, and consequently, as water will flow in B just as easily as in A,

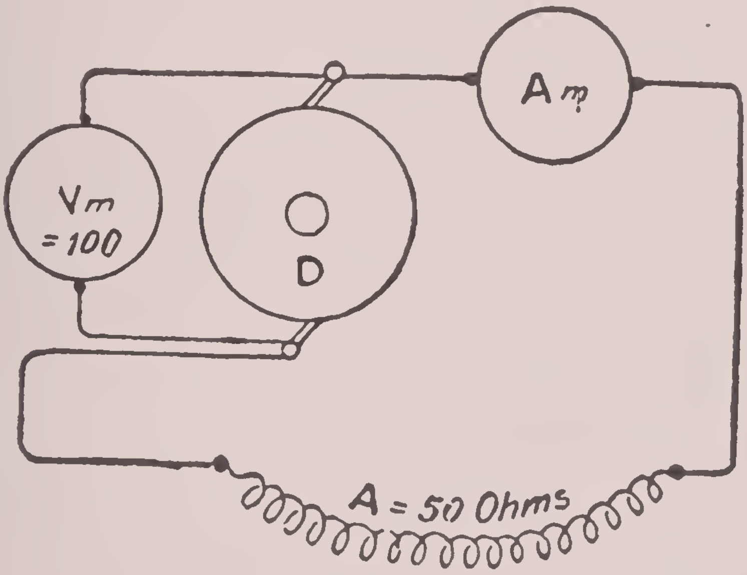

Fig. 141. A Series Circuit.

the resistance to the passage of water from C to D would be halved, and the current gauge would immediately indicate twice the former current. The two pipes in parallel are really equivalent to one pipe of twice the internal sectional area. The same thing would apply to 3, 4, 10, or any number of similar pipes joined between C and D; the resistance would be reduced to ½, ¼, or 1/10 its former value, with a corresponding increase in the current flowing through the pump.

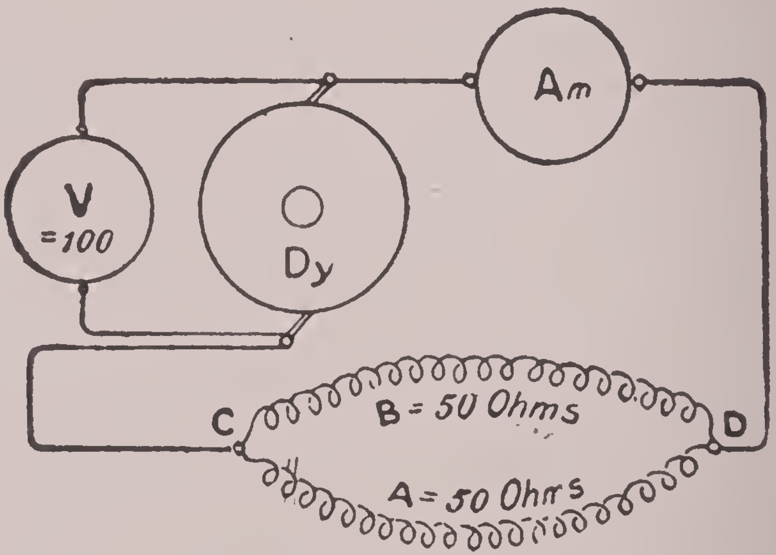

Fig. 142. Parallel Circuits.

It must be understood that there is no increase in the current flowing through any individual pipe when others are connected across. The current in A, Fig. 143, for instance, would remain practically constant throughout providing the pump maintained the same difference of pressure.

It is in this way that we must look upon the electrical current in Fig. 142. The more similar wires we join between C and D, the more are we increasing the conductivity between these two points, and the less is the resistance becoming, but providing the dynamo maintains the pressure, no alteration would take place in the value of the current in any individual conductor. Each separate conductor would act according to Ohm's law, and each being joined to points, maintained the same difference of potential, and each being of the same resistance, each must have the same strength of current flowing through it.

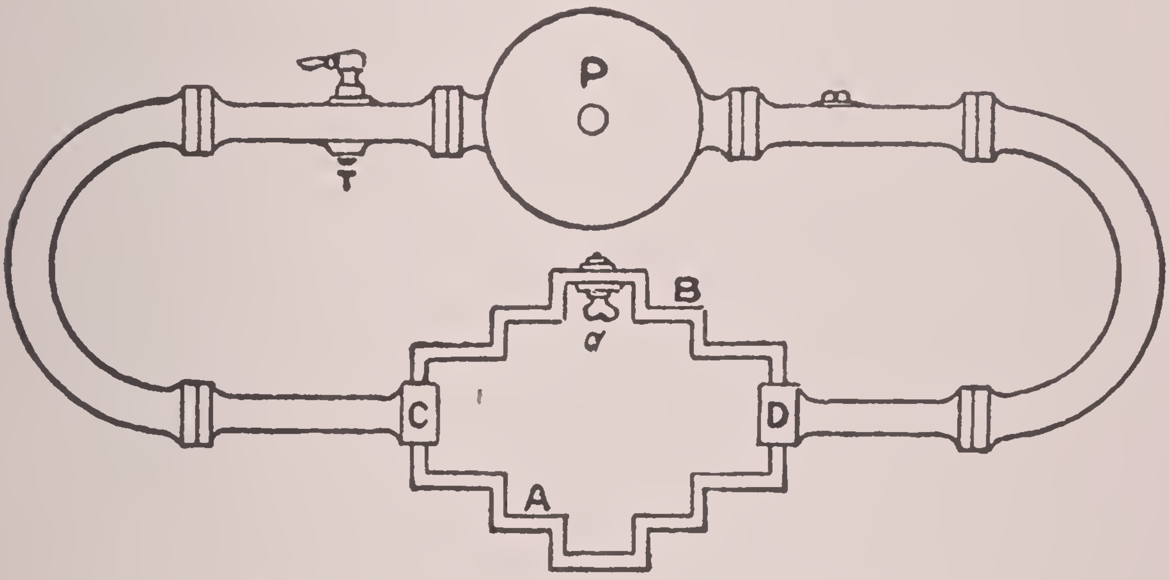

Fig. 143. Hydraulic Circuit with By-pass.

Effects of Current.

Imagine a circuit like Fig. 144 containing in order:

1. A galvanometer or current meter.
2. An electromagnet.
3. An apparatus for electrolysing water or a gas voltameter.
4. A copper plating bath or copper voltameter.

5. A vessel containing a coil of wire submerged in water, and surrounded with a box of sawdust to prevent the radiation of the heat.

6. An incandescent lamp.

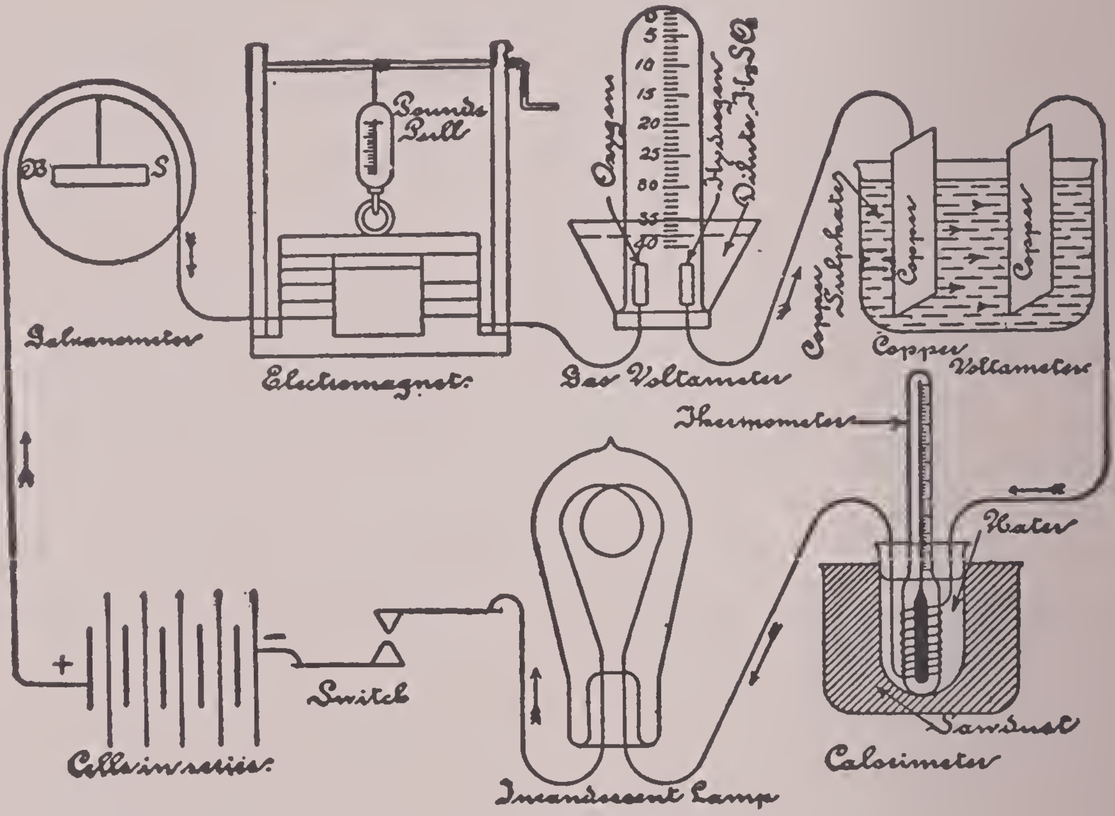

Fig. 144. The Different Effects of Current.

When the current is flowing you will observe the following effects:

1. The needle is deflected.
2. Armature of magnet is attracted and held.
3. Water is turned to oxygen and hydrogen gases.
4. The cathode is copper plated.
5. The thermometer rises.
6. The lamp gives light.

Now let us examine the size of each of these effects, measuring them in the most suitable units, and then let the current be changed from its original value to say twice and then three times that value and see how the size of the effect varies.

The *Galvanometer* gives readings of 10, 15, 17 degrees, so that the effect of a given current varies according to whether it is the only current passing or one of many equal currents.

The Electro-magnet gives 9 lbs. pull, then 11 lbs., and finally 11½ lbs.; so that evidently the attraction of a magnet does not increase in the same proportion as the increase of current in its coils.

In the *Gas Voltameter* we find that double the current electrolyses double the quantity of water, and three times the current, treble the water. The same is true of the *Copper Plating Bath.* The amount of metal deposited is exactly proportional to the current and the time. A given current deposits 0.0026 pounds of copper per hour; double the current will deposit 0.0052 pounds, treble the current 0.0078 pounds.

The thermometer in the *Calorimeter* has risen very rapidly. The original current made it rise 1/10 of a degree a second, twice the current gave a rise of 4/10 degrees and thrice the current gave 9/10 degrees rise.

Since 1 x 1 equals 1
and 2 x 2 " 4
and 3 x 3 " 9

And since the numbers 1, 2 and 3 represent the currents; and 1, 4, 9 the heat produced, we say that the heating is proportional to the square of the current.

(The product obtained by multiplying a number by itself is called the square of that number).

The extra amount of *Light* obtained by increasing the current is small and does not increase regularly. The first increase in current adding 3 candle power, and the next increase added 4 candle power, while the next would have probably added 6 candle power.

Looking back over these current effects it will be seen that the electrolysis or electro-chemical effect is the only one that is regular in a simple manner, so we choose the amount of *copper* or *silver plating* done as the test for the size of the current flowing. We decide that the unit of current shall be called an

AMPERE, which is the current depositing 0.0026 pounds of copper or 0.00887 pounds of silver per hour. Although a certain current may be lighting a lamp, if that current were made to silver plate and deposited 0.00443 pounds in ½ hour, we should call it an ampere.

The original Edison Meters were nothing but zinc plating baths put into the customers line and by the amount of plating done the amount of current drawn by the lamps was known.

Modern meters are either galvanometers marked to show amperes or are small motors with a cyclometer attachment to record the ampere-hours.

An ampere-hour is one ampere for one hour, half an ampere for two hours, etc.

LESSON 18.

RESISTANCE.

Every conductor offers more or less opposition to the flow of electricity and we call the opposition Resistance.

In order to compare the resistance of different materials some standard of resistance must be agreed upon. All electricians and engineers have settled on the

OHM. The unit of resistance is the ohm, which is the same resistance as is offered by a mercury conductor made in this way: Take 0.0318 of a pound of pure mercury and pour it into a glass tube which is exactly 41.88 inches long, and of uniform size of bore. The mercury must exactly fill the tube when both are at a temperature of 32 degrees Fah. Try different sized tubes of the same length (41.88 inches) until one is found to be exactly filled. Then the resistance offered by this conductor to the passage of electric current is called one ohm. Remember that the temperature must always be 32 degrees.

Mercury is selected because it is a liquid and because its resistance is high and so the tube is not inconveniently long.

To measure all resistances the ohm is used, but to express very small resistances the microhm is used. It is one millionth of an ohm.

To express very high resistances the megohm is used, It is one million ohms. It is abbreviated meg.

A telephone engineer would refer to a resistance of 0.00385 ohms as 3850 microhms. Ohms × 1,000,000 = microhms.

In speaking of the resistance between the two track rails measured across the ties an engineer would probably say 47.5 megs instead of 47,500,000 ohms.

Ohms ÷ 1,000,000 = megohms.

Laws of Resistance.

The resistance varies with the nature of the material. The metals are good conductors, cotton and dry goods very poor conductors, while silk, porcelain, shellac, oils, mica, paraffin, and dry air are so poor that we call them insulators.

If we take a piece of wire having a known resistance, and cut it into two equal lengths, we find on measuring that each piece has just half the resistance of the former piece, hence the law is twice the length, twice the resistance.

Stated mathematically it is—

The resistance of a given wire of uniform section is proportional to its length.

But the resistance also depends on the cross section of the wire. If we take three wires of the same material, but with cross sections, of 1, 2 and 3 circular mills,* if the first one has 1 ohm resistance, the others will have ½ and ⅓ of an ohm resistance.

Hence the greater the area of wire's cross section the less the resistance.

The resistances are inversely proportional to their cross sectional areas.

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*See further on in Lesson.

It must be remembered that the cross sectional area is obtained by squaring the diameter. If the diameters of two wires are 3 and 6 mils, their areas are 9 and 36 circular mils and the resistance of the first wire is 4 times as great as the second, because the area is only ¼ of the second.

The resistance of conductors also varies very largely with the nature of the material used. For instance, if we take three different wires, all the same length, and the same sectional area, but one made of copper, another of iron, and the third of german silver, their resistances would be in the ratio of 1:6:13. It is useful to remember these figures as being approximately correct, for the three metals named are in great demand in electrical engineering.

German silver made of 2 parts copper, 1 of zinc and 1 of nickel, is an extra high resistance metal. and is useful when we need a lot of resistance in a small space. The resistances used to aid in the starting of traction motors are usually of cast iron.

Stated briefly, the longer the piece of material the higher is the resistance, and the greater its cross section the lower the resistance. The rule being:

$$\text{Resistance in ohms} = \frac{\text{Material x Length}}{\text{Cross Section.}}$$

The number representing the materials are the ohms resistance of a piece 1 foot long and 1 mil in diameter.

Copper	10.8	Iron	63.4
Aluminum	17.2	Mercury	128.3
German Silver	586.2		

For Length insert the number of feet and for Cross Section put the square of the diameter in mils (thousandths of an inch).

For example: Find the resistance of 9000 ft. of iron wire 0.2 inch in diameter.

Material: Iron 63.4. Length in feet 9000

Diameter in mils 200. Squared 40000

$$\text{Resistance in ohms} = \frac{63.4 \times 90000}{40000} = 14.26$$

This rule only applies to round wires but may be changed so as to apply to rectangular conductors.

$$\text{Resistance} = \frac{\text{Material} \times \text{Length}}{\text{Area} \times 1.27}$$

Area being the area of the cross section of rod in square mils.

An increase in the temperature increases the resistance of the metals, but they each have their own way of increasing, some faster than others.

The resistance of copper increases a little less than ¼ of 1% for every degree Fahr. and iron increases a little more than copper. Mercury increases about 1/40 of 1% per degree.

Wire Measurement.

The diameter of a round wire or bar is always measured in mils. A mil is a thousandth of an inch.

The area of round wires is measured in Circular mils. The number of circular mils is found by squaring the diameter measured in mils.

This is a far better way of measuring than the mechanics way of square inches, but cannot be applied to rectangular pieces of material.

To make matters as simple as possible the electrician measures the two dimensions of the cross section in mils and obtains the area (by multiplying them together) in square mils. This he converts at once to circular mils by multiplying by 1.27. Then having circular mils he can apply formulas.

The mil-foot is used in formulas and is handy as a comparison of resistances.

A piece of round material 1 foot long and 1 mil in diameter is a mil-foot.

Resistance and Conductivity.

If we take a piece of wire whose resistance is 1 ohm, and apply an E. M. F. to the ends of it, we find that it is able to conduct electricity. We might say that this piece of wire has unit conducting power, or unit conductivity, as well as unit resistance. If we take another piece of the same wire, but twice the length of the former piece, it will have twice the resistance, that is, it will conduct electricity only half as well as the former piece, consequently we should say this piece of wire has resistance of 2 ohms and a conductivity of ½. Again, if we take a wire having a resistance of 10 ohms, then it will conduct electricity only 1/10 as well as the piece having 1 ohm. Therefore we should say its conductivity is 1/10, and so on.

We thus see that the conductivity of a substance is the reciprocal or the reverse of its resistance. If the resist-

TABLE OF DIMENSIONS OF PURE COPPER WIRE.*

No. B. & S.	Diam. Mils.	Area.		Weight and Length, Sp. Gr. 8.9.		
		Circular Mils.	Square Mils.	Lbs. per 1000 feet.	Lbs. per Mile.	Feet per Pound.
0000	460.000	211600.0	166190.2	640.73	3383.04	1.56
000	409.640	167805.0	131793.7	508.12	2682.85	1.97
00	364.800	133079.0	104520.0	402.97	2127.66	2.48
0	324.950	105592.5	82932.2	319.74	1688.20	3.13
1	289.300	83694.5	65733.5	253.43	1338.10	3.95
2	257.630	66373.2	52129.4	200.98	1061.17	4.98
3	229.420	52633.5	41338.3	159 38	841.50	6.28
4	204.310	41742.6	32784.5	126.40	667.38	7.91
5	181.940	33102.2	25998.4	100.23	529.23	9.98
6	162.020	26250.5	20617.1	79.49	419 69	12.58
7	144.280	20816.7	16349.4	63.03	332.82	15.86
8	128.490	16509.7	12966.7	49.99	263.96	20.00
9	114.430	13094.2	10284.2	39.65	209.35	25.22
10	101.890	10381.6	8153 67	31 44	165.98	31.81
11	90.742	8234.11	6467.06	24.93	137.65	40.11
12	80.808	6529.94	5128 60	19.77	104.40	50.58
13	71.961	5178.39	4067.07	15.68	82.792	63.78
14	64.084	4106.76	3225.44	12.44	65.658	80.42
15	57.068	3256.76	2557.85	9.86	52.069	101.40
16	50.820	2582.67	2028.43	7.82	41.292	127.87
17	45.257	2048.20	1608.65	6.20	32.746	161.24
18	40.303	1624.33	1275.75	4.92	25.970	203.31
19	35.890	1288.09	1011.66	3.90	20.594	256.39
20	31.961	1021.44	802.24	3.09	16.331	323.32
21	28.462	810.09	636.24	2.45	12 952	407.67
22	25.347	642.47	504.60	1.95	10.272	514.03
23	22.571	509.45	400.12	1.54	8.1450	648 25
24	20.100	404.01	317.31	1.22	6.4593	817.43
25	17.900	320.41	251.65	.97	5.1227	1030 71
26	15.940	254.08	199.56	.77	4.0623	1299 77
27	14.195	201.50	158.26	.61	3.2215	1638.97
28	12.641	159.80	125.50	.48	2.5548	2066.71
29	11.257	126.72	99.526	.38	2.0260	2606.13
30	10.025	100.50	78.933	.30	1.6068	3286.04
31	8.928	79.71	62.603	.24	1.2744	4143.18
32	7.950	63.20	49.639	.19	1.0105	5225.26
33	7.080	50.13	39.369	.15	.8015	6588.33
34	6.304	39.74	31.212	.12	.6354	8310.17
35	5.614	31.52	24.753	.10	.5039	10478.46
36	5.000	25.00	19.635	.08	.3997	13209.98
37	4.453	19.83	15.574	.06	.3170	16654.70
38	3.965	15.72	12.347	.05	.2513	21006.60
39	3.531	12.47	9.7923	.04	.1993	26487 84
40	3.144	9.88	7.7635	.03	.1580	33410.05

---

* 1 mile pure copper wire = 13.59 ohms at 15.5° C. or
1-16 inch. diam. 59.9° F.

1 circular mil is .7854 square mil.

ance of a conductor be 50 ohms, its conductivity is 1/50. A name has been given to the unit of conductivity which is easy to remember. Seeing that the conductivity is the reverse of resistance, the name of the unit of resistance (ohm) has been reversed for that of conductivity. Thus a wire of 1 ohm resistance has 1 mho conductivity. A wire of 75 ohms resistance has a conductivity of 1/75 mho, while a wire of ½ ohm resistance has a conductivity of 2 mhos.

Of course it will be understood that if conductivity is the reciprocal of resistance, then resistance is also the reciprocal of conductivity, one the reverse or reciprocal of the other. Therefore a wire of 1/50 mho conductivity has a resistance of $\frac{1}{\frac{1}{25}} = 50$ ohms.

Resistances in Series and in Parallel.

When resistances are in series we add their values together to get the total resistance but when they are in parallel the resistance of the group, called joint resistance, is less than the smallest and must be calculated in a certain manner.

Turn back to Fig. 142. A can conduct electricity across between A and D its conductivity being 1/50 mho, that is, it will conduct electricity across only 1/50 as well as a resistance of ohm. But we have now got two paths, each with a conductivity of 1/50 mho, so the two together can conduct electricity across twice as well as one of them, for now we have a conductivity of 1/50+1/50 =1/25 mho. We have already seen that resistance is the reciprocal of conductivity, therefore the resistance between C and D is now $\frac{1}{\frac{1}{25}} = 25$ ohms. But it was 50 ohms before we joined the second wire across, so that we have reduced the resistance to half its former value.

If there should be resistances in series with those in parallel figure the joint resistance of the set in parallel and then figure the rest as if that joint resistance took the place of the parallel group and everything were in series.

Consider Fig. 145. Here we have C and D joined by two wires, A having a resistance of 50 ohms, and B having a resistance of 25 ohms.

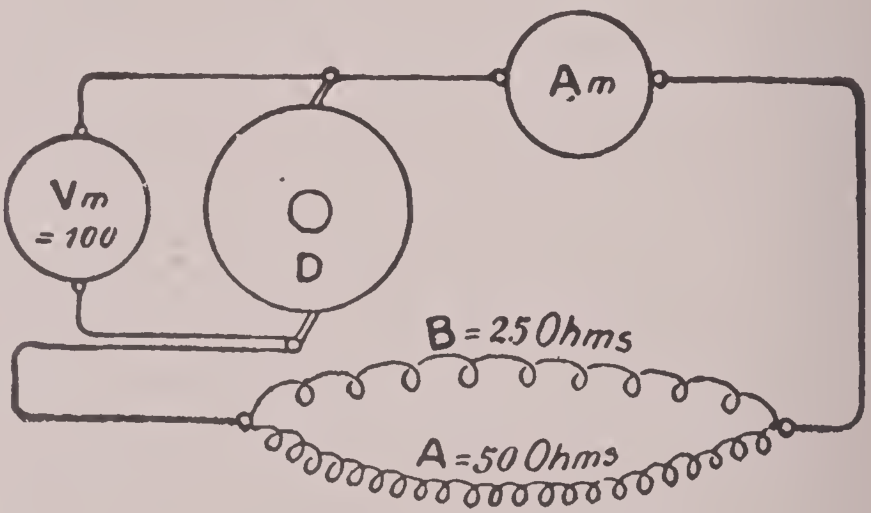

Fig. 145. A Divided Circuit.

Now we have seen that A has a conductivity or conducting power=1/50, similarly B has a conductivity=1/25, and therefore the two together have a conductivity of 1/50+1/25=3/50 mho. The resistance between C and D being the reciprocal of the conductivity

$$\text{is } = \frac{1}{\frac{3}{50}} = \frac{50}{3} = 16.6 \text{ ohms}$$

(less than the smallest resistance).

The current flowing through the dynamo now is—

$$C=\frac{E}{R}=\frac{100}{16.6}=6 \text{ amperes.}$$

Again, imagine C and D to be connected by three wires, A=50 ohms, B=25 ohms, and G=10 ohms. Then the conductivity between

$$C \text{ and } D=\frac{1}{50}+\frac{1}{25}+\frac{1}{10}=\frac{1+2+5}{50}=\frac{8}{50} \text{ mho,}$$

and the resistance between

$$C \text{ and } D=\frac{1}{\frac{8}{50}}=\frac{50}{8}=6.25 \text{ ohms}$$

(again less than the smallest resistance joining C and D).

Of course the combined resistance must be less than that of the smallest resistance between the points, for if G were there alone, that part of the circuit would have 10 ohms resistance, and the addition of B and A, though larger than G, is only diminishing the resistance between these points by opening up other paths for the passage of electricity.

Q. 1. What is the resistance of four wires in parallel of 2, 5, 10, and 20 ohms respectively?

The combination has a conductivity of—

$$\frac{1}{2}+\frac{1}{5}+\frac{1}{10}+\frac{1}{20}=\frac{10+4+2+1}{20}=\frac{17}{20} \text{ mho,}$$

and their combined resistance in parallel

$$=\frac{1}{\frac{17}{20}}=\frac{20}{17} \text{ ohms.}$$

Q. 2. Two mains are carrying current for a group of twenty lamps; each lamp has a resistance when incandescent (white hot) of 160 ohms, and they are all joined in parallel. What is the resistance between the two mains.

Here all the resistances are equal and the total resistance is 1/20 of one of them or 160÷20=8 ohms.

If we have only to deal with *two* resistances in parallel, it will be easier and quicker to make use of this rule:

The joint resistance of two resistances in parallel is *the product of the two divided by their sum.*

Q. 3. Two resistances of 5 ohms and 20 ohms are in parallel. What is their combined resistance?

$$R = \frac{\text{product}}{\text{sum}} = \frac{5\times20}{5+20} = \frac{100}{25} = 4 \text{ ohms}$$

Working by the first method we have:

$$\text{Conductivity} = \frac{1}{5} + \frac{1}{20} = \frac{5}{20}$$

$$\text{Resistance} = \frac{20}{5} = 4 \text{ ohms.}$$

LESSON 19.

OHM'S LAW.

We have now stated what an ampere of current and an ohm of resistance are. The unit of pressure is the result of these two, for a volt is the pressure necessary to send one ampere of current through one ohm of resistance.

Knowing these three units of measurement and the law of flow of current we can solve many electrical problems.

Law of the Flow of Current.

With a given circuit the greater the pressure the greater the current, or if the pressure (voltage) remains the same, the less the resistance the more current flows.

Hence *Current* equals *Pressure* divided by *Resistance,*

$$\text{or Amperes} = \frac{\text{volts}}{\text{ohms}}$$

This is the regular form of Ohms Law and means:

The current in amperes in any conductor is equal to the difference in pressure between the ends of the conductor, in volts; divided by the resistance between the ends, expressed in ohms.

Expressed as a formula, Ohms Law is

$$C = \frac{E^*}{R} \text{ or } C = \frac{V}{R} \text{ or } C = \frac{PD}{R}$$

By E we mean the E. M. F., or electromotive force, that is the total pressure in the circuit measured in volts.

By V we mean the pressure (in volts) in the part of the circuit we are considering.

By P. D. we mean the Pressure Difference or difference in pressure (in volts) between the ends of the part of the circuit we are considering.

It is evident that V and PD are the same, while E is the sum of all the V's in the circuit.

The form $V = CR$ means:

(1) The voltage required to maintain a current flow of C amperes through R ohms is given by the product of C and R.

(2) The drop of pressure or voltage lost in any conductor is equal to the product of the current C and resistance R.

In fact, the loss in pressure which always occurs when transmitting current is often called the CR loss. The "drop" is the usual term.

The form $R = \frac{E}{C}$ is used to find what resistance must be used in connection with a pressure E to limit the current to C amperes.

---

*Electrical magazines and many text books use I for current, reserving C for capacity. It will soon be generally adopted by every one; but for a student C is more convenient and expressive.

Problem 1. An incandescent lamp having a resistance when hot of 240 ohms is connected to mains having 120 volts pressure between them. How much current does the lamp draw?

$$C=\frac{V}{R}=\frac{120}{240}=\tfrac{1}{2}\text{ ampere.}$$

Problem 2. What pressure will be required to force 7 amperes through an arc lamp whose resistance hot is 7 ohms?

$$V=CR=7\times 7=49\text{ volts.}$$

Problem 3. What drop will there be in transmitting 2000 amperes to a locomotive 2 miles from power house, with a circuit whose resistance is 1/20 of an ohm per mile?

$$2\text{ miles}=2/20=1/10\text{ ohms.}$$

$$\text{Drop}=V=CR=2000\times 1/10=200\text{ volts.}$$

Problem 4. In a car heater enough heat is generated when 10 amperes are flowing. Five of them are to be placed in series in a car. Voltage between third rail and track 500. What must be the resistance of the heater when hot?

$$500\text{ volts}\div 5\text{ heaters}=100\text{ volts per heater.}$$

$$R=\frac{V}{C}=\frac{100}{10}=10\text{ ohms.}$$

Problem 5. In Fig. 146 let the dynamo of 0.01 ohms resistance be producing 100 volts as measured on the volt meter V. This is not the E. M. F. of the dynamo, because there is some drop in the dynamo. The 100 volts is the V. or P. D. at the ends of the external circuit.

This external circuit contains resistances as follows: A in series 2 ohms. C and E together in parallel, yet in series as a group with A. C is 100 ohms, E is 300 ohms. B is 3 ohms in series with A and the parallel group.

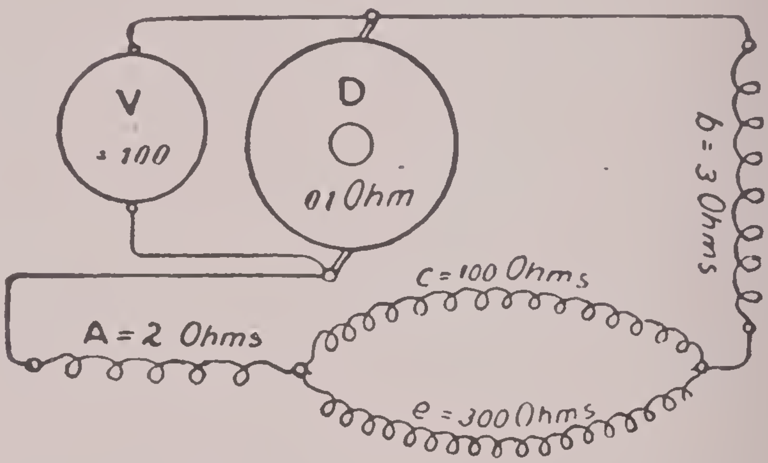

Fig. 146. Dynamo in a Series—Parallel Circuit.

What current flows through the dynamo?

The same current as through A or B for the circuit is a series one. The resistance of external circuit is as follows:

$$\begin{array}{lr} A= & 2 \text{ ohms} \\ C+E \text{ jointly}= \dfrac{\text{product}}{\text{sum}} = \dfrac{30000}{400} & =75 \text{ ohms} \\ B= & 3 \text{ ohms} \\ \hline & \text{Total}=80 \text{ ohms} \end{array}$$

A circuit of 80 ohms has 100 volts pressure at its ends, therefore,

$$C=\frac{V}{R}=\frac{100}{80}=1.25 \text{ ampere flows.}$$

The drop in the dynamo must be

$$V = CR = 1.25 \times 0.01 = 0.0125 \text{ volts.}$$

A trifling amount, it is true, but should the dynamo deliver 1000 amperes the drop becomes 10 volts, which is large enough to be considered. If the voltmeter were placed around A what would it read? It would read the drop in A.

$$CR = 1.25 \times 2 = 2.5 \text{ volts.}$$

Grouping Cells or Dynamos.

A cell or dynamo is a source of E. M. F. and is in addition a source of resistance.

When we wish a higher voltage than one cell on machine will give, we connect several in series. This increases the voltage and resistance and the result depends on the resistances of the external and internal circuit. The part of circuit in the cells or dynamos is the internal circuit.

Problem 1. Six blue stone cells, each 1 volt E. M. F. and 3 ohms resistance, are in series on a 100 ohm external circuit. Add 6 more in series. Will the current be doubled? Ri and Re are abbreviations for internal and external resistances.

$$\begin{array}{rl} & \text{Cell Ri} = 3 \text{ ohms} \\ \text{6 cells Ri} = 18 \text{ ohms} & \text{E M F} = 1 \text{ volt} \\ \text{Re} = 100 \text{ ohms} & \text{E M F} = 6 \text{ volts} \\ \hline \text{R} = 118 \text{ ohms} & \end{array}$$

$$C = \frac{E}{R} = \frac{6}{118} = 0.05 \text{ (nearly) amperes.}$$

Add 6 more.

$$\begin{array}{r} Ri = 36 \text{ ohms} \\ Re = 100 \text{ ohms} \\ \hline 136 \text{ ohms} \end{array} \qquad E\ M\ F = 12 \text{ volts}$$

$C = 12/136 = 0.09$ (nearly) amperes.

Answer: The current is almost doubled.

Problem 2. The same cells as in Problem 1 are connected to external circuit of 1 ohm and 6 more cells are added in series. Is the current doubled?

$$\begin{array}{r} 6 \text{ cells } Ri = 18 \text{ ohms} \\ Re = 1 \\ \hline R = 19 \end{array} \qquad EMF = 6 \text{ volts.}$$

$C = \frac{E}{R} = \frac{6}{19} = 0.32$ (nearly) amperes.

Adding 6 in series

$$\begin{array}{r} Ri = 36 \text{ ohms} \\ Re = 1 \text{ ohm} \\ \hline R = 37 \text{ ohms} \end{array} \qquad EMF = 12 \text{ volts}$$

$C = \frac{E}{R} = \frac{12}{37} = 0.32+$ amperes.

Answer. No. Practically no increase of current.

Moral: With high external resistance add more E. M. F. in series to increase current (the added resistance does no harm). With low external resistance add nothing in series unless it has a very low internal resistance.

Suppose in Problem 2 we had added 3 storage batteries at 2 volts and 0.33 ohms each.

Old Ri=18
New Ri= 0.99
Re= 1.
R=20 ohms

Old EMF=6
New EMF=6
E=12 volts

$$C=\frac{E}{R}=\frac{12}{20}=0.6 \text{ amperes.}$$

Which is practically double the previous current.

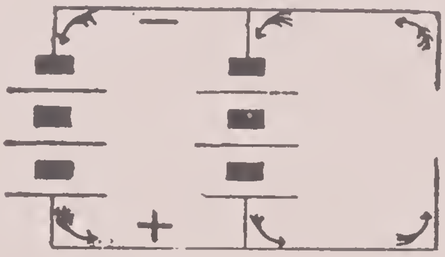

Fig. 147. Batteries in Parallel.

In Problem 2 had there been nothing available except 6 more blue stone cells they should have been put in parallel with the others, similar to Fig. 147.

Each set of 6 cells has Ri=18 but joint resistance of two groups is 9 ohms.

Ri= 9 ohms
Re= 1 ohm
R=10 ohms

The E. M. F. of each set of 6 cells is 6 volts and the E. M. F. of the two groups not adding together makes E. M. F. of group, 6 volts as before.

$$C = \frac{E}{R} = \frac{6}{10} = 0.6 \text{ amperes,}$$

which is practically double the previous current. Hence, when external resistance is low, lower your internal resistance by adding more cells in parallel.

There is a silly rule:

The best arrangement of cells is when the internal and external resistances are equal.

This is an arrangement to force the battery to deliver the greatest possible current. The efficiency will be 50% because since Ri and Re are equal the drop in each is the same, hence half the pressure is doing useless work and half useful work.

For economy have internal resistance low as compared with external resistance.

When a battery is at work on a high resistance line, add cells in series to increase current. When external resistance is low always add cells in parallel.

These rules do not apply to most dynamos because their internal resistance is very low.

With dynamos to get more voltage place extra machines in series. You will then get more current also.

To get more current at same voltage place extra machines in parallel with the first one.

LESSON 20.

METERS.

Galvanometers.

We have already seen in Lesson 12 that a current passing near a magnetic needle deflects it; also that a current passing first over a magnetic needle and then back under it in opposite direction deflects the needle further.

By a few simple tests you can convince yourself that increasing the current would increase the deflection.

An instrument consisting of a coil of wire carrying the current to be tested, and a magnet; the two being so arranged that one can be deflected, is called a galvanometer.

There are two types, the Thompson and the D'Arsonval.

The Thompson type has the coil of wire stationary and the light magnetic needle suspended by a silk thread. These can be made more sensitive than the other type, but are not portable and external fields have a great influence on them, causing them to give false indications. This is prevented by thick soft iron cases, much too heavy to be carried around.

The silk suspension makes the needle sensitive to vibration.

It is a fine laboratory instrument and with modified construction has been used in the workshop and field, but for this work the D'Arsonval is much better.

The D'Arsonval type has a very small light coil of wire suspended by a fine bronze wire between the poles of a stationary magnet. Since the movable part is not a magnet except during the actual instant of the test, outside magnetic fields have no influence on its motion. To shield it during test a thin soft iron or steel case is put on the instrument which does not affect its portability. These covers are usually copper, brass or nickel plated for appearance sake, but the actual material is iron for the purpose of shielding the instrument.

These D'Arsonval galvanometers are not so sensitive as the other type, which for ordinary work is a great advantage.

Both of these types have the needle swinging over a circular scale divided into degrees, or may have a small mirror attached so that the deflection may be read by the motion of a spot of light moving along a long ruler supported about a yard away from galvanometer.

As mentioned before, twice the current does not give twice the deflection but by sending known currents through a galvanometer and marking a scale with pen and ink we could make an ampere meter. This is called Calibration.

Ammeters and Voltmeters.

The ammeters and voltmeters of commercial work are all special adaptations of the D'Arsonval galvanometer or for the least accurate work such as on switchboards; they are of the magnetic vane type.

The Weston instruments are D'Arsonval galvanometers.

Fig. 148 shows an instrument with the cover removed. A large permanent magnet of U shape is supported by a gun-metal casting screwed to the ends of the limbs, and the whole of the working part is built up on this magnet independent of the case, so that the movement can be removed bodily from the case by simply taking out one screw which holds the gun-metal casting in place. The inside polar faces of the magnet are surfaced up so as to come closely into contact with wrought-iron pole pieces which are bored out to about 1 in. diameter, and fixed rigidly in their place with screws passing through the limbs of the magnet. To these pole pieces a second gun-metal casting is screwed, which forms a support for a soft iron cylinder ¾ in. diameter inside the bored out pole pieces, and also a support for the scale. The soft iron cylinder fills up most of the space between the pole pieces, allowing an air space at either side of ⅛ in., and in this space a fairly strong, uniform, magnetic field exists. A coil of fine insulated copper wire of about twelve turns is wound on a thin brass frame, large enough to embrace the soft iron cylinder, with freedom to move in the space between it and the pole pieces. This is pivoted in jewelled bearings which are screwed to the pole pieces, but insulated from them, forming little bridges across, and the ends of the coil are connected to these bridge pieces by spiral springs, one at the top and the other at the bottom of the coil, the springs being wound in opposite directions, so that when one is twisted up by a movement of the coil the other is untwisted. This arrangement corrects for any variation in temperature, for the effect on one spring would be counteracted

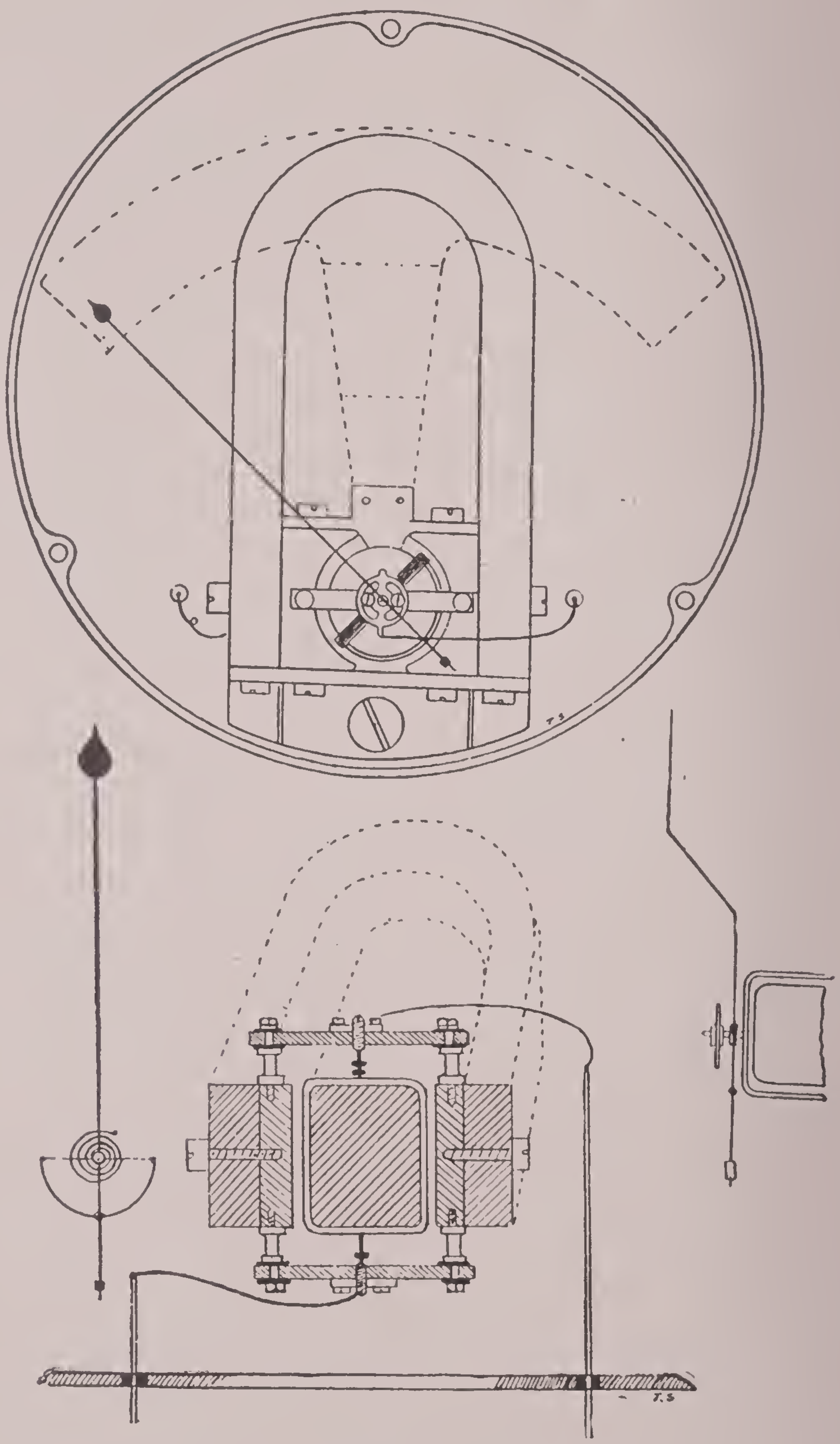

Fig. 148. Interior of Weston Instrument.

by the opposite effect on the other. The coil normally lies at 45° to the line joining the poles of the magnet, and consequently the magnetic field created by a current in the coil will be displaced relatively to the field of the horseshoe magnet as shown in Fig. 149, and the lines twist the coil through a certain angle against the action of the spiral springs, the angular movement of the coil depending on the strength of the current in the coil and the strength of the field in which it is placed.

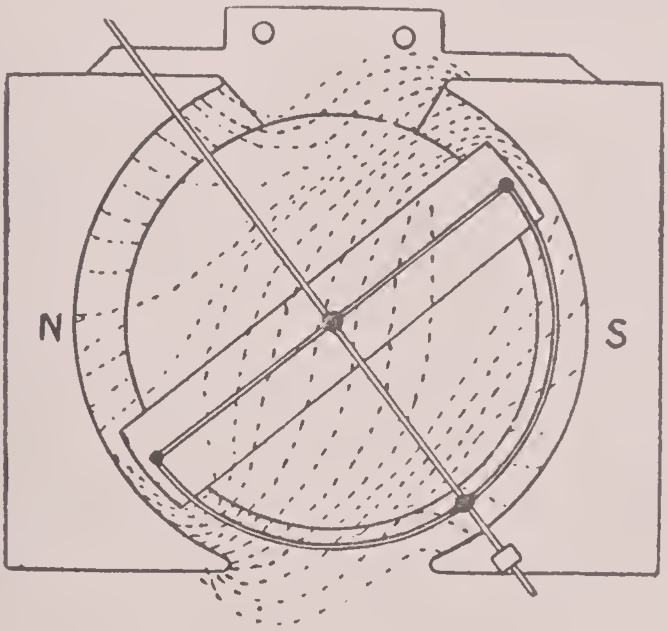

Fig. 149. Diagram of Magnets, Flux, Coil and Inner Core of Weston Instrument.

To the coil is attached a pointer of aluminum, the whole being balanced so that the instrument can be read in any position, and the pointer and scale are bent up so as to come near the front of the case.

A perspective view of movement is shown in Fig. 150.

In this instrument the whole current does not go through the coil, but only a small fraction of it. The main part of the current crosses from one terminal to the other by a broad strip of metal under the base of the instrument, while the coil is placed as a shunt across the terminals, or as a conductor in parallel with the metal strip (Fig. 151), and consequently the ratio of

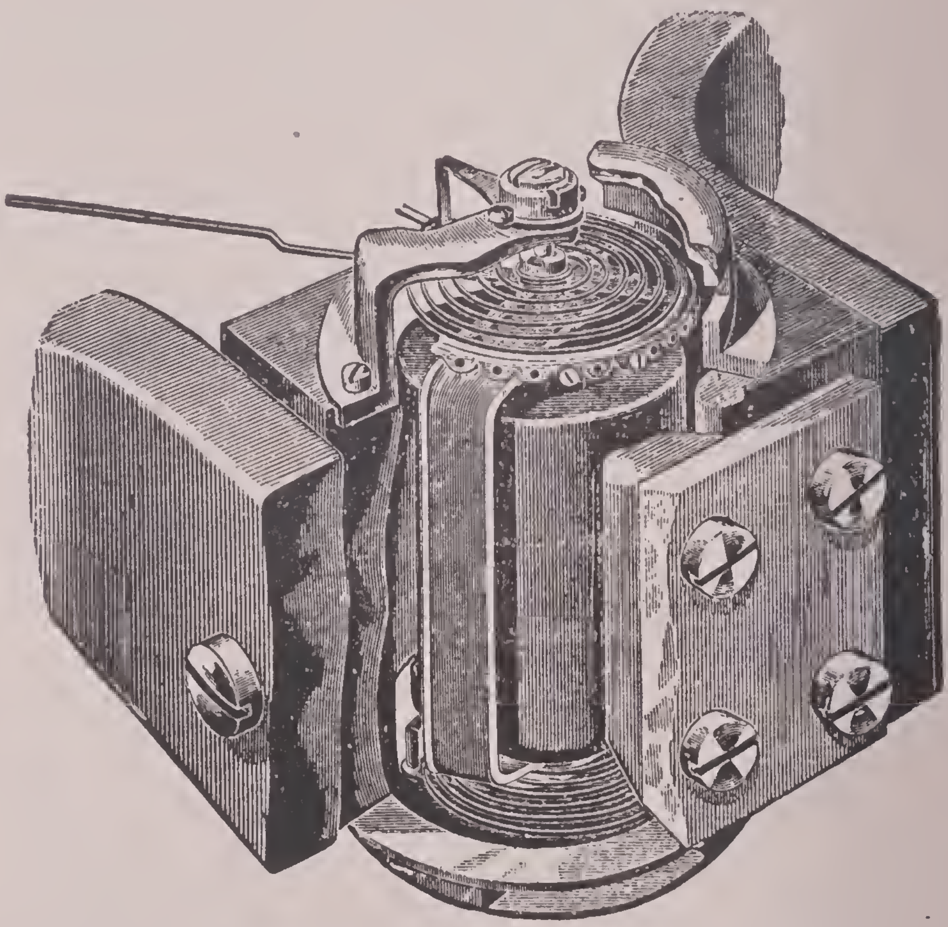

Fig. 150. View of Movement of Weston Instruments.

the currents in the strip and in the coil will be inversely proportional to their resistances. Now with a given strength magnetic field due to the magnet, and a given elasticity of the spiral springs, it will require a certain number of ampere turns in the coil to produce the full deflection on the scale. This can be secured by adjusting the resistance of the strip connecting the terminals so that the same movement will do for any instrument. Thus, suppose the instrument were required to read to a maximum of 10 amperes, and we required 1 ampere in the coil to give the maximum deflection,* then the resistance of the coil must be 9 times that of the strip, so that the current will divide at the terminals, 9/10

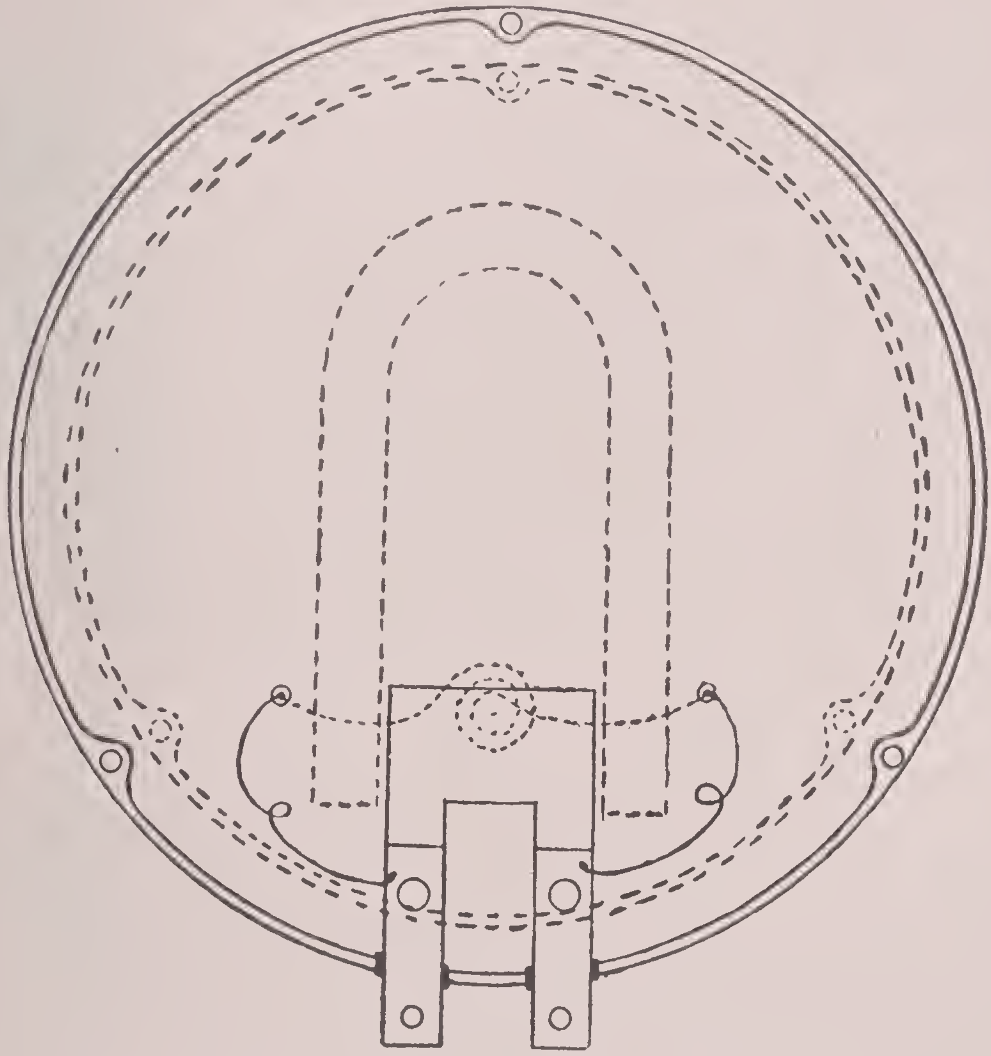

Fig. 151. Magnet and Shunt of Weston Ammeter.

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*It actually takes 1/100 amperes.

going through the metal strip and 1/10 through the coil. If the instrument is required to read to a maximum of 100 amperes, then the metal strip must have 99 times less resistance than the coil, and the current will then divide at the terminals, 99/100 going through the strip and 1/100 going through the coil, which will give a reading to the full range of the scale as before. By the arrangement of the pole pieces and wrought iron cylinder the field due to the permanent magnet is practically uniform over the range of movement of the coil, and so

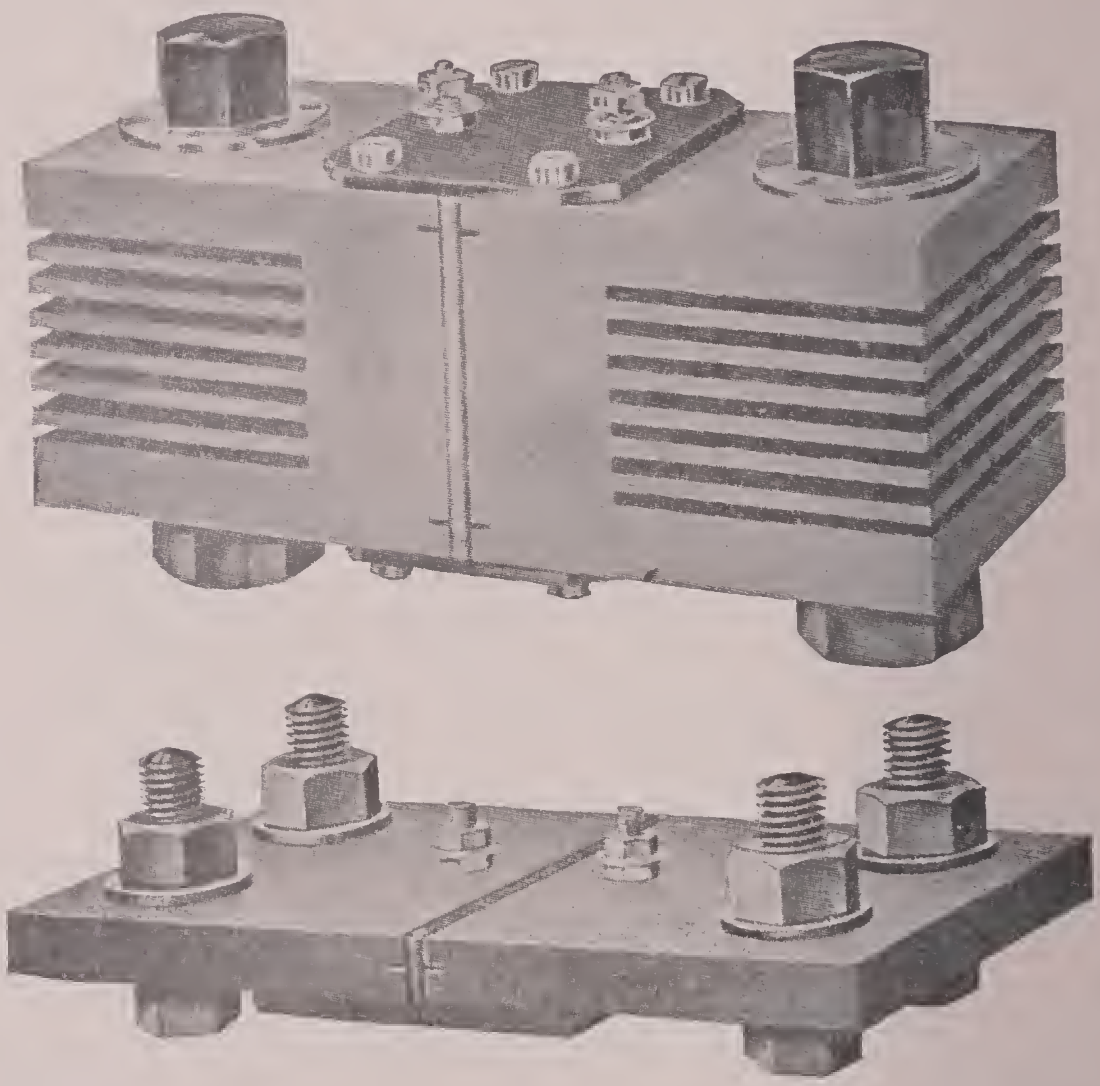

Fig. 152. External Shunts for Ammeters. 1000 and 5000 Ampere Sizes.

the scale readings are the same size throughout. Should the permanent magnet vary in strength, the instrument would not read correctly, but the magnets are so treated that the falling off in strength over a number of years is inappreciable.

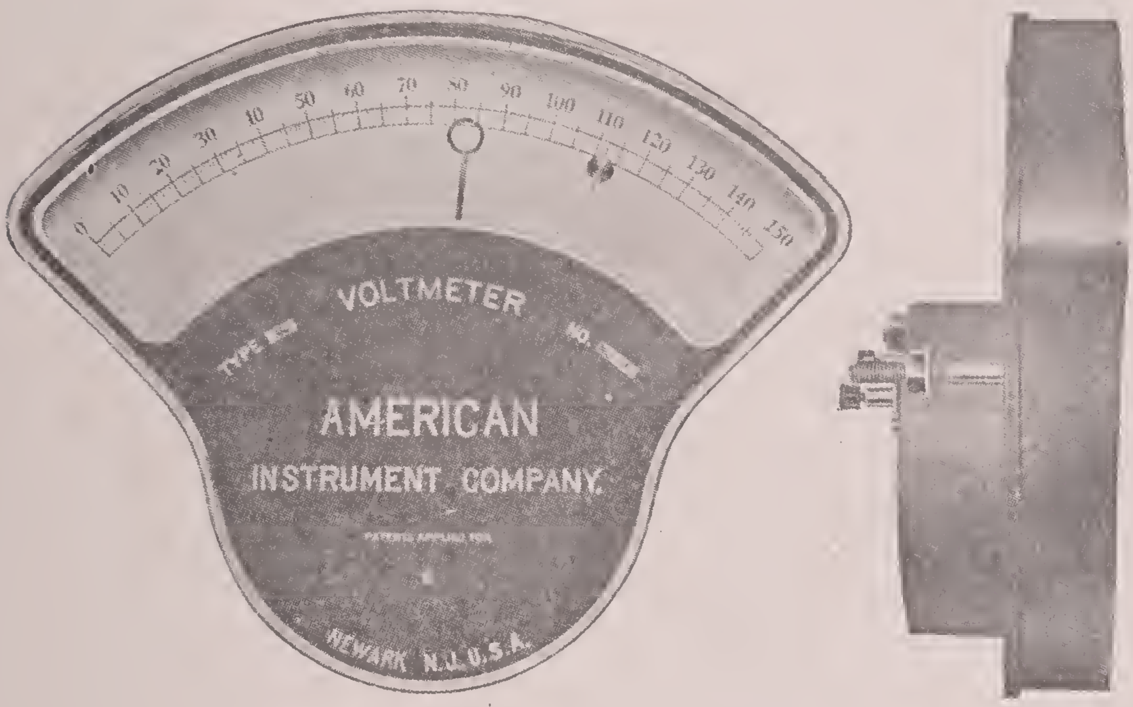

Fig. 153. Switch Board Instrument.

The strip or shunt for portable instruments is always inside the case, while for switchboard instruments the shunt is too large (Fig. 152) and is placed separately on the back of the board. Leads* are run along the board to the meter terminals which project through holes in the board from the meter which is in front.

Such a switchboard instrument is shown in Fig. 153 and Fig. 154.

A voltmeter is made by removing the metal strip or shunt connecting the terminals and placing a resistance coil in series with the moving coil.

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*Technical name for wires.

As it takes 1/100 amperes to swing the pointer over full scale for every volt the instrument reads, it must have 100 ohms in the resistance coil.

A 500 volt instrument will have 500,000 ohms resistance, and hence 1/100 amperes will flow through the moving coil.

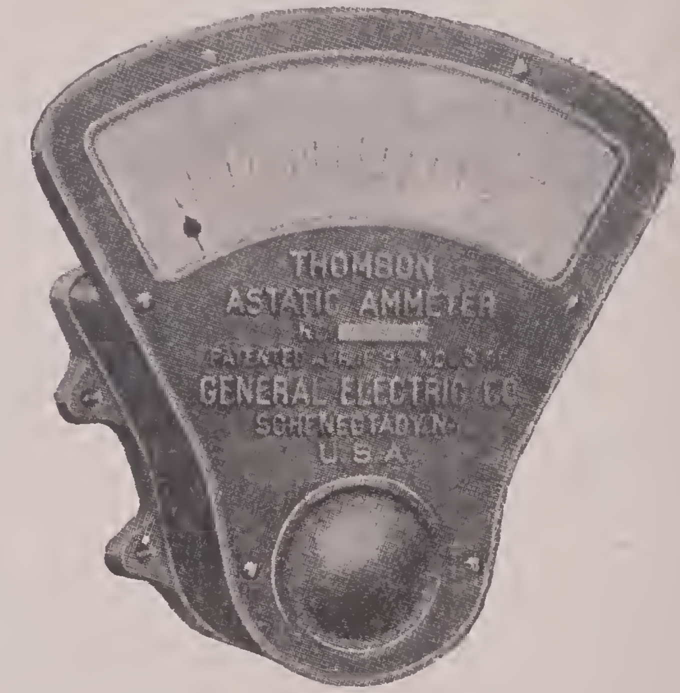

Fig. 154. Switch Board Ammeter.

The moving coil is wound on a copper or aluminum frame, which when it swings has current induced in it by the magnets and stops vibrating very quickly; in fact you cannot detect any vibration. The needle seems to move to a certain spot and stop dead. This is called a "dead beat" needle; a more scientific name is "aperiodic."

Some instruments have electro-magnets instead of permanent magnets. The Thomson Astatic instruments are of this type. Two of these instruments are shown in Figs. 154 and 155. This latter has a scale or dial of opal glass with an electric light behind it. This makes the instrument easily read from a distance or at night. These are called "illuminated dial instruments."

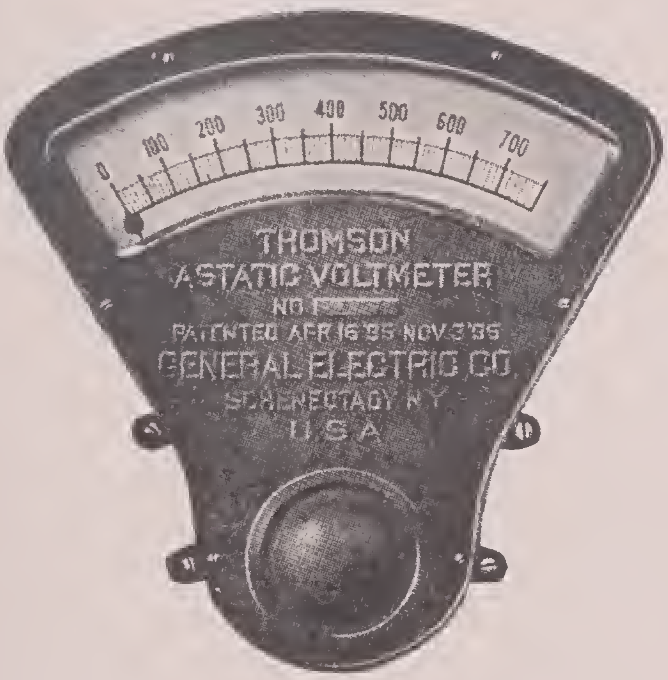

Fig. 155. Illuminated Dial Instrument.

The instrument of Fig. 153 has an extra hand ending in a ring. This can be set at the voltage you wish to maintain. The most hasty glance will then tell you whether your voltage is too high or too low.

In order to save space on switchboards some instruments are made thin and broad and are set horizontally or vertically.

Fig. 156 shows the exterior and interior of a Thomson Edgewise Ammeter.

The Thomson Inclined Coil instruments as shown in Fig. 157 are portable instruments used for alternating current only. In an emergency they can be used to measure direct current by reading, reversing current, reading again and averaging results.

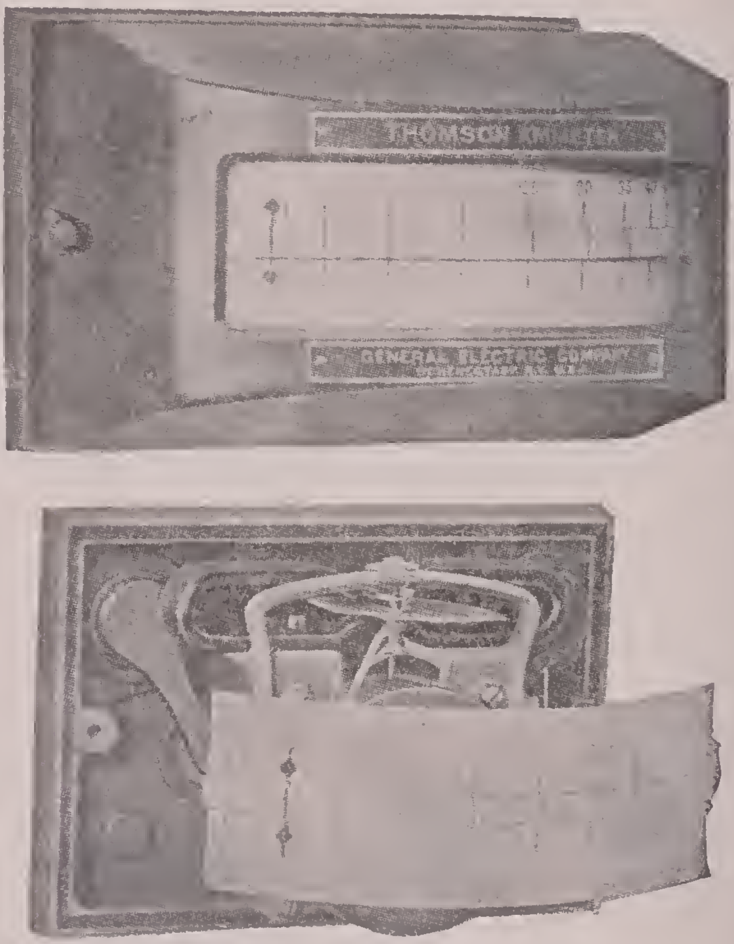

Fig. 156. Thomson Horizontal Ammeter.

The action of the magnetism of the inclined coil is twist the inclined sheet iron vane "a" around to the dotted line position.

The Weston instruments described are for direct current only. The company makes an alternating current voltmeter but no ammeter. Thomson Astatic instruments are for direct current. The Thomson Inclined Coil in portable, or edgewise switchboard form is for alternating current.

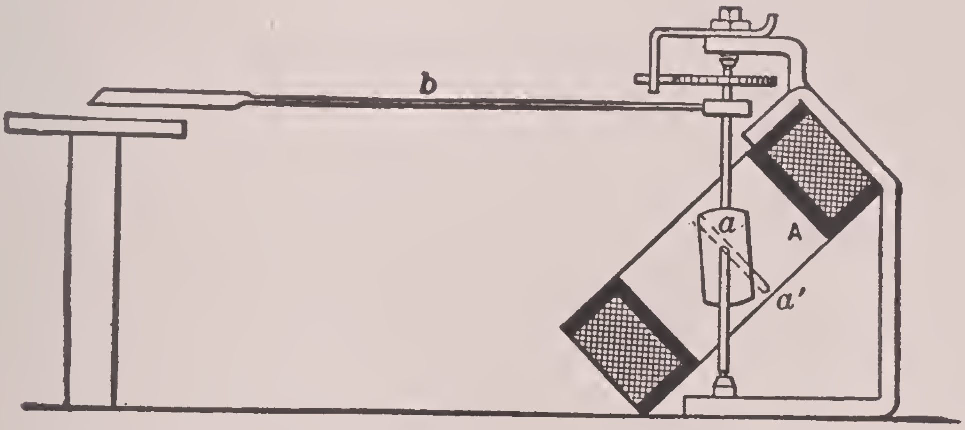

Fig. 157. Thomson Inclined Coil Instrument.

Wattmeters.

By combining two coils, one movable, the other stationary, one attached as a voltmeter with series resistance, the other attached as an ammeter, with a shunt, we get an instrument whose needle indicates power or watts. These are called indicating wattmeters.

The recording wattmeter records watt-hours. A watt-hour is one watt of power used for an hour, or any combination like one-quarter of a watt for four hours, etc.

The Thomson Recording Watt-Hour Meter is used for direct or alternating current. It is shown with dust-proof case removed in Fig. 158. The connections made to it are shown in Fig. 159. By "light" in the figure must be understood any load at all.

The meter consists of an electric motor whose armature A is supplied with current from the mains through a high resistance P in the back of the instrument and a small field coil on right-hand side.

This armature is in shunt across the circuit, hence its current is proportional to the voltage.

The main current passes through the field F, hence the strength of the field is proportional to the current.

The speed of the motor is therefore proportional to both current and voltage, that is to the power or watts.

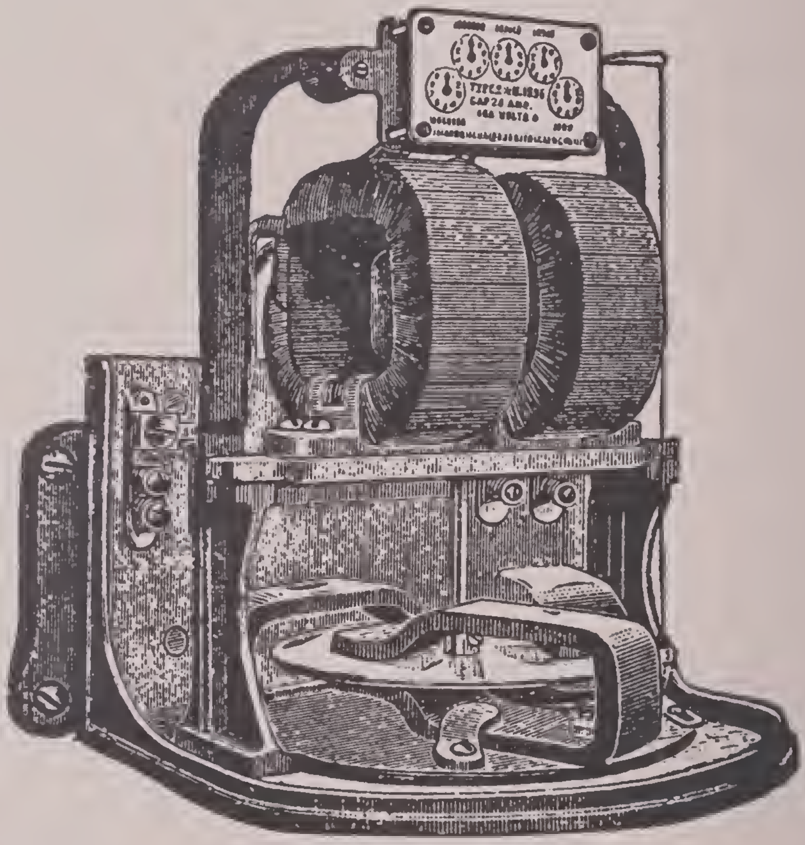

Fig. 158. Thomson Recording Watt-hour Meter.

The armature shaft goes on past the commutator to a cyclometer with dials like a gas meter. The revolutions are here recorded as watt-hours.

The auxiliary field is just strong enough to nearly overcome the friction in the bearings and cyclometer, so that the smallest current through the mains will produce rotation.

At the bottom of the armature shaft is an aluminum disk revolving between the poles of permanent magnets. This device prevents the meter from running at too great a speed and gives an adjustment for accuracy.

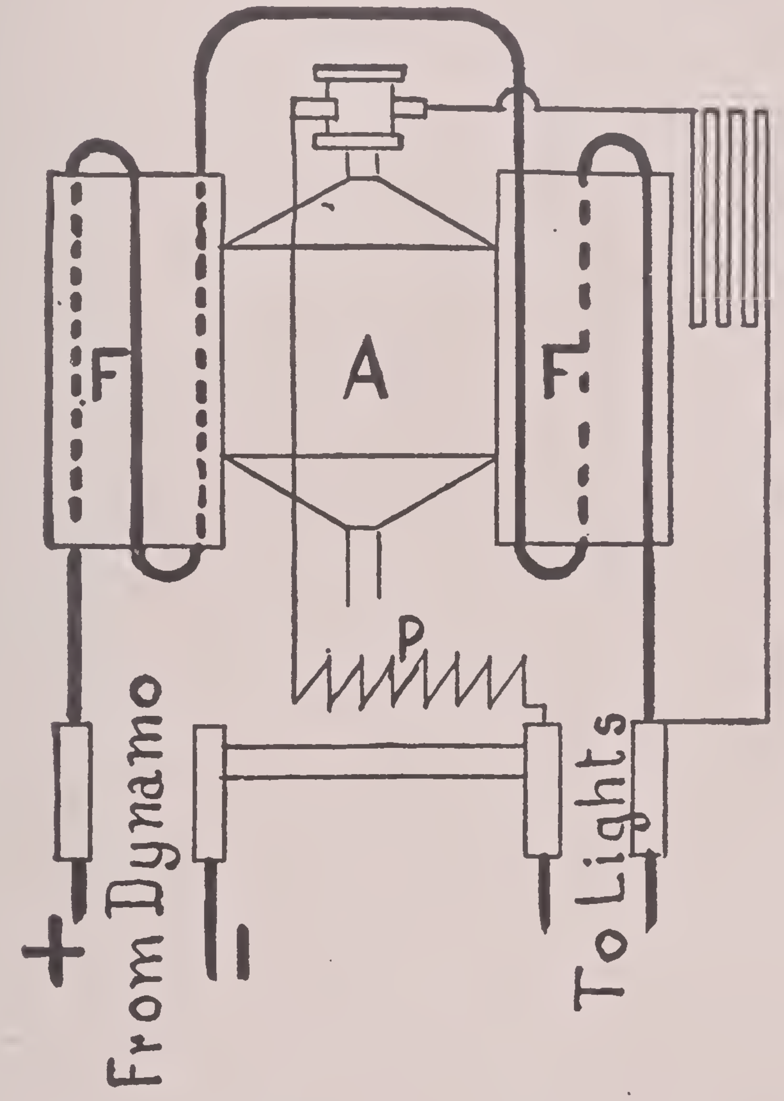

Fig. 159. Diagram of Connections. Thomson Recording Watt-hour Meter.

The further out the magnets are swung the faster is the motion of the metal passing between their poles and the greater a retarding effect they produce.

A meter running too slow from age or dirty bearings could be brought up to proper speed by swinging the magnets in a little.

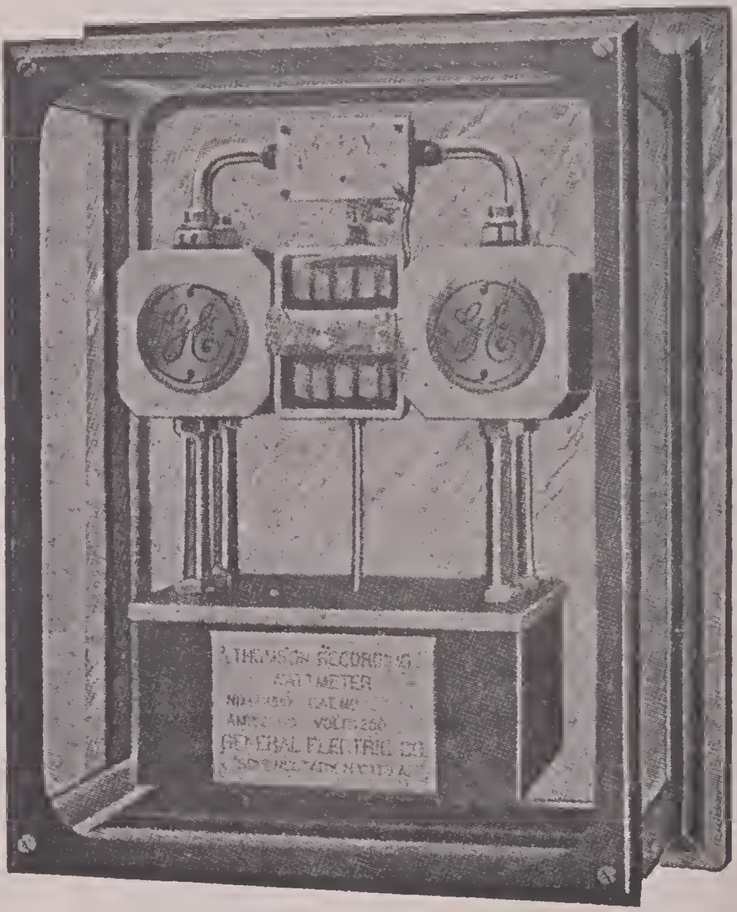

Fig. 160. Large Capacity Thomson Recording Watt-hour Meter.

For large currents the appearance of the meter is quite different, as is shown in Fig. 160. The retarding device is enclosed in a case and the whole instrument enclosed in a dust-proof glass case.

LESSON 21.

Electrical Work, Power and Efficiency.

FORCE.—Force is defined as that which produces motion, or a change of motion; thus force must always be applied to any body to cause it to move. To increase, decrease, or stop this motion, that is to change it, force must again be applied. For example, to start a loaded wheel-barrow force must be applied, either by pushing or pulling it, but when it is set in motion less force will be required to keep it in motion; to cause a change in motion, that is to increase or decrease the speed, extra force must be applied. Force does not always produce motion, but only tends to produce it, as when a man tries to push a laden freight car he applies all his muscular force, but no motion results.

DIFFERENT KINDS OF FORCE.—There is the force of gravitation, which causes all bodies free to move to fall from a higher to a lower level. The force exerted by a man riding a bicycle or a horse drawing a carriage are examples of muscular force. An engine draws a train of cars by reason of the mechanical force applied, which is due to the expansion of the steam in the steam cylinder. A mixture of air and illuminating gas in a room is ignited and the explosion wrecks the room; the action is due to the chemical force exerted. The force which produces or tends to produce a flow of electricity is electromotive force. The rate at which a train moves depends upon the force exerted by the engine, so also, the rate of flow of electricity depends upon the amount of electromotive force applied.

MASS AND WEIGHT.—The mass of a body is the quantity of matter in it; the weight of a body is due to the force of gravity acting upon this matter. Since the force of gravity diminishes as we ascend from the earth's surface, the attraction for a mass of matter will diminish, or it will weigh less on the top of a high mountain than at the sea level; the mass of matter, however, would be the same in each case. Weight is not, therefore, the same thing as mass, but we can conveniently measure a body by its weight.

WORK.—Work is done when force overcomes a resistance, or, work is force acting through space $(W = F \times S)$.

$$\text{Work} = \text{Force} \times \text{Distance},$$

$$\text{or Work} = \text{Pounds} \times \text{Feet} = \text{Foot-pounds}.$$

Work is not always done when a force acts; for instance, a man pushes with all his force against a brick wall; he is exerting force, but doing no work because no motion results, nor is any resistance overcome. If a weight be lifted, work is done directly in proportion to the weight and to the distance through which it was moved. Thus, the work done in lifting 4 pounds to the height of 3 feet is equivalent to 12 foot-pounds of work. Exactly the same work is performed when two pounds are lifted 6 feet; or 6 pounds raised 2 feet; or 12 pounds raised 1 foot. Work does not always consist in raising weights; the steam engine does work by hauling a train, due to the expansive force of steam acting upon the piston; an explosion of powder in a cannon causes an iron ball to traverse a certain distance. The magnetic action in a dynamo sets up a force which causes a current to flow through an electric motor and the motor drives a car weighing so many pounds a certain number of feet every minute, hence the total foot-pounds of work are performed electrically. The work in each case is measured in foot-pounds. Whether work be done mechanically, chemically, thermally,* or electrically, it can be expressed in foot-pounds. The total amount of work done is independent of time, that is, the same work may be performed in one hour or one year. When different amounts of work performed in different times are to be compared, then reference is made to the time, or rate of working, or the power.

POWER.—Power is the rate at which work is done, and is independent of the amount of work to be done.

$$\text{Power (rate of working)} = \frac{\text{Work}}{\text{Time}} = \frac{\text{Foot-pounds}}{\text{Time}} = \text{Foot-pounds per unit of time.}$$

For example, it requires four hours for a particular engine to draw a train from one station to another, while another engine may draw the same train the same distance in two hours. One engine is thus twice as powerful as the other, because it can do the same work in half the time. When the train has reached its destination it would have represented the same amount of work done, no matter whether it had traveled at one mile per minute or one mile per hour, leaving, of course, friction and air resistance out of account.

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*By heat.

Power is estimated according to the amount of work done in a given period of time. As mechanical work is measured in foot-pounds, mechanical power would thus be so many foot-pounds per minute, or per second. The mechanical unit of power is the horse power.

One Mechanical Horse Power=33000 ft. lbs. per Minute

$$\text{or } \frac{33000}{60} = 550 \text{ ft. lbs. per Second.}$$

If a body weighing 33000 pounds be raised one foot every minute then we have a rate of working equal to one horse power; or if 16500 pounds be raised two feet per minute, the rate of working is the same, one horse power. If the work were continued at the same rate for one hour, we would have a larger unit of work, or the horse-power-hour. When we say that an engine is developing 40 horse power we mean that it is performing 550×40=22000 foot-pounds of work every second.

DIFFERENCE BETWEEN ENERGY, FORCE, WORK AND POWER.—It is important that the student should thoroughly understand the meaning of the above terms. *Energy* is the capacity to do work. *Force* is one of the factors of work and has to be exerted through a distance to do work, the work being reckoned as the product of the force and the distance through which it has been applied. *Work* is done when energy is expended or when force overcomes a resistance. *Power* is the rate of working.

ELECTRICAL WORK.—Work is force acting through space, or energy expended, therefore, resistance is overcome when work is performed. Force may exist without work being performed, as when you push against a table and do not move it, no work is done, yet the force exists. An electrical force exists between the two terminals of a battery, tending to send a current of electricity from one to the other through the air. The force is not sufficient to overcome the resistance of the air, therefore no current flows and the battery is not doing any work; the same is true with a dynamo when running on open circuit. When a wire is connected across the battery terminals, the force overcomes the resistance of the wire and electricity is moved along, around or through the wire, which becomes heated. The electrical work, or energy expended, in this case, is represented by the amount of heat generated. With a small lamp connected to the battery, the work is represented by the heat and light given by the lamp as well as the heat given to the remainder of the circuit. The total work performed is the product of the force, the current, and the time that the current is maintained or

$$\text{Electrical Work} = \text{Volts} \times \text{Amperes} \times \text{Time.}$$

But the engineer is not interested much in work—the element of time is of great importance to him, so he always figures power used.

ELECTRICAL POWER.—Power is the rate at which energy is expended, and is independent of the total work to be accomplished. The rate of working, or the power, is found by dividing the total work by the time required to perform it.

$$\text{Electrical Power} = \frac{\text{Electrical Work}}{\text{Time.}}$$

The unit of electrical power is a unit of work performed in a unit of time, and is called a *Watt.*

$$\text{Power}=\text{Volts}\times\text{Amperes}=EC.$$

Problem 1. A current of 2000 amperes flows at a pressure of 600 volts. What power is used?

$$\text{Watts}=EC=600\times2000=1200000.$$

To avoid the use of large numbers the Kilowatt is used. It is 1000 watts.

The answer to Problem 1 is therefore 1200 K. W. (Kilowatts abbreviated K. W.).

Problem 2. How many K. W. will an alternator producing 11000 volts and 272 amperes give?

$$\begin{aligned} W=EC&=11000\times272\\ &=2992000 \text{ watts}\\ &=3000 \text{ K. W. (nearly)}. \end{aligned}$$

A watt is a small unit, for it takes 746 watts of electrical power to exert the same power as one horse power of steam power.

Hence 746 watts=1 horse power (H. P.)
and ¾ K. W.=1 H. P. (approx.)
1 K. W.=1⅓ H. P. (approx.)

A rough rule for figuring is:

To change from K. W. to H. P. add on ⅓ of the number, from H. P. to K. W., subtract ¼ of itself from the number.

A very convenient formula for power is obtained in this way:

$$W=EC, \text{ but } C=\frac{E}{R}$$

$$\text{hence } E=CR, \text{ so } W=CR\times C=C^2R.$$

This means the watts power used up in any resistance is found by the formula $W=C^2R$. The square of the current multiplied by the resistance.

This is all wasted power and is often referred to as the "C square R loss."

When a current goes through a motor it produces some mechanical power, but when flowing through a wire it produces nothing but magnetism and heat. This is often referred to by saying a current produces C^2R heat, meaning that the current produces C^2R watts which turn to heat.

EFFICIENCY.

When we bring 223.8 K. W. of energy to a motor and turn out at its pulley 240 H. P., it is because some of the energy has been lost in the transformation from electrical to mechanical power.

223.8 K. W.=223800 watts.

223800÷746=300 H. P.

$$\text{Efficiency}=\frac{\text{Output}}{\text{Intake}}$$

Both being expressed in same units,

$$\text{efficiency}=\frac{300}{240}=0.8.$$

Efficiencies are usually multiplied by 100 and then called per cent. Efficiency of 0.8 would be called 80% efficiency.

CIRCUIT BREAKERS.

In its simplest form a circuit breaker is merely a switch so designed as to be capable of frequently opening the circuit carrying its full current without any damage to itself.

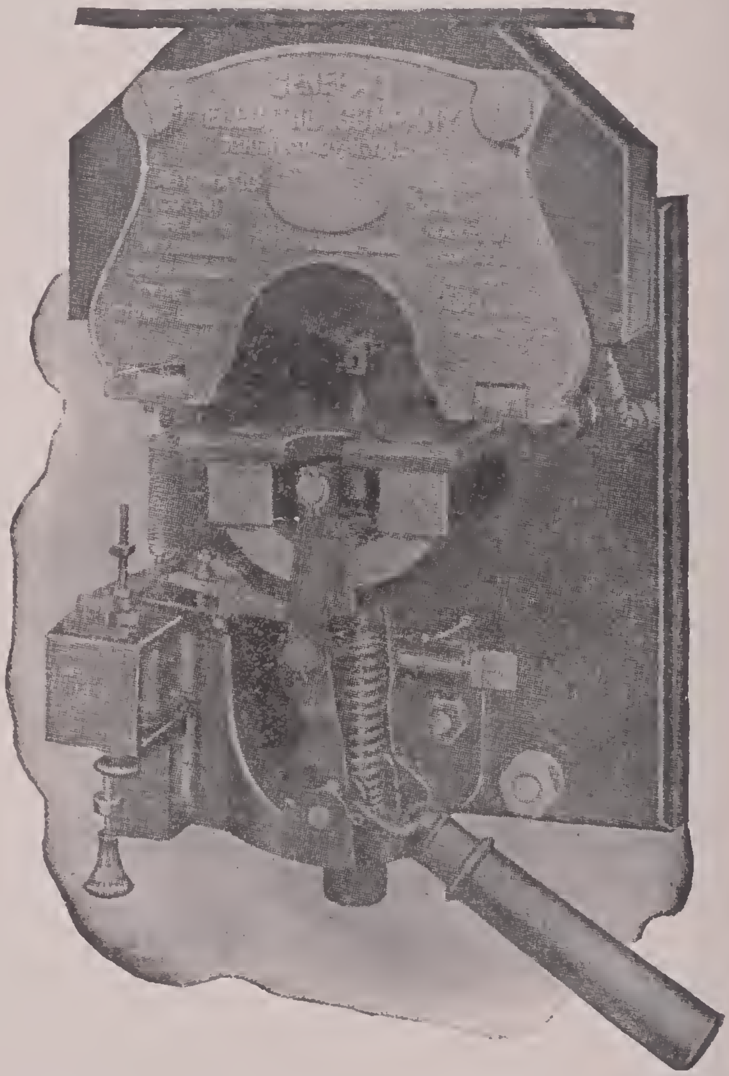

Fig. 161. Automatic Circuit Breaker with Low Voltage Release, Tell-tale Switch and Magnetic Blow-out.

With the large currents handled in railroad work it has become necessary to define a switch as "a piece of apparatus to close circuits."

Apparatus to open circuits* are now called circuit breakers, trip switches, oil switches or some other special name.

In order to have a good contact for carrying current where breaker is closed, this contact is of copper.

As shown in Fig. 161, the contact is composed of two large copper blocks against which press the ends of a curved copper brush. This brush is made of numerous thin sheets of copper, pressed together so as to form an almost solid block of metal. They are held together tightly in the middle, and the ends left free.

When the brush is pressed upwards against the blocks it makes a peculiar scratching or rubbing contact in which each separate leaf of the brush makes its own contact, and holds it with a firm pressure owing to the springiness of the copper.

The scratching or rubbing contact ensures the removal of all dirt or oxidized copper from the block and the individual action of each leaf makes a good contact, utilizing the total surface of the brush.

While such a contact is an excellent carrier of current, it is the worst possible breaker of a current, for the separate leaves would melt on the edges and fuse together.

The breaker is arranged so that a second contact of a carbon plug in a carbon socket always closes before and opens after the main copper contacts.

In Fig. 161 this secondary carbon contact is on the end of the rod which passes up into the hollow formed by the nameplate.

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*It will be understood that after breaking a current by a circuit breaker the mere opening of a knife switch cannot be called opening a circuit, because after the breaker opens there is no electrical circuit.

In Fig. 162 the carbon plug is K and the sides of the socket are marked G. The main contact blocks are the squares and the copper brush is marked H.

The toggle which closes and opens the breaker is marked F.

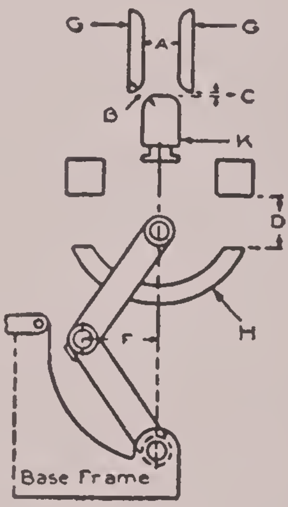

Fig. 162. Diagram of Fig. 161.

In Figs. 163 and 164 the carbon contacts are seen at the top in the shape of carbon blocks. In Fig. 163 the main contact is plainly shown below, while in Fig. 164 the main contact is concealed by a metal housing.

The mechanical connection between the main (copper) contacts and the secondary (carbon) contacts has enough lost motion that the main contact is well opened before the secondary opens.

What has been described constitutes a circuit breaker, but a circuit breaker is always an automatic device. An oil switch may or may not operate automatically, but when we say circuit breaker we always mean an automatic one.

The circuit breaker is set by hand against a spring and held shut, closed, or set (the three words meaning the same thing) by a latch or hooked catch. There is a rod one end of which is arranged to unfasten or trip the catch, the other end is fastened to an iron armature or core.

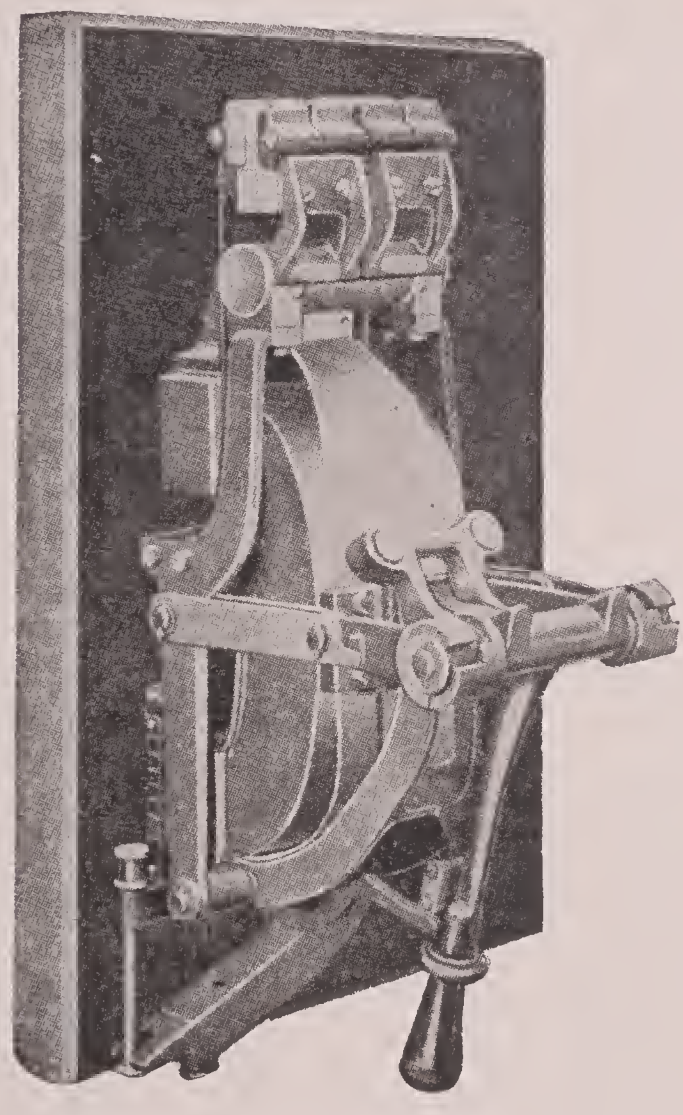

Fig. 163. Large Capacity Breaker. Carbon Break Type 2000 to 10000 Amperes.

All the current in the particular circuit which the breaker is in passes through a solenoid which exerts an attraction on the core or armature.

Suppose the normal current on the line to be 700 amperes, then the circuit breaker would have contacts of sufficient area and a solenoid of such a size that 700 amperes could pass through the breaker 24 hours a day without overheating any part.

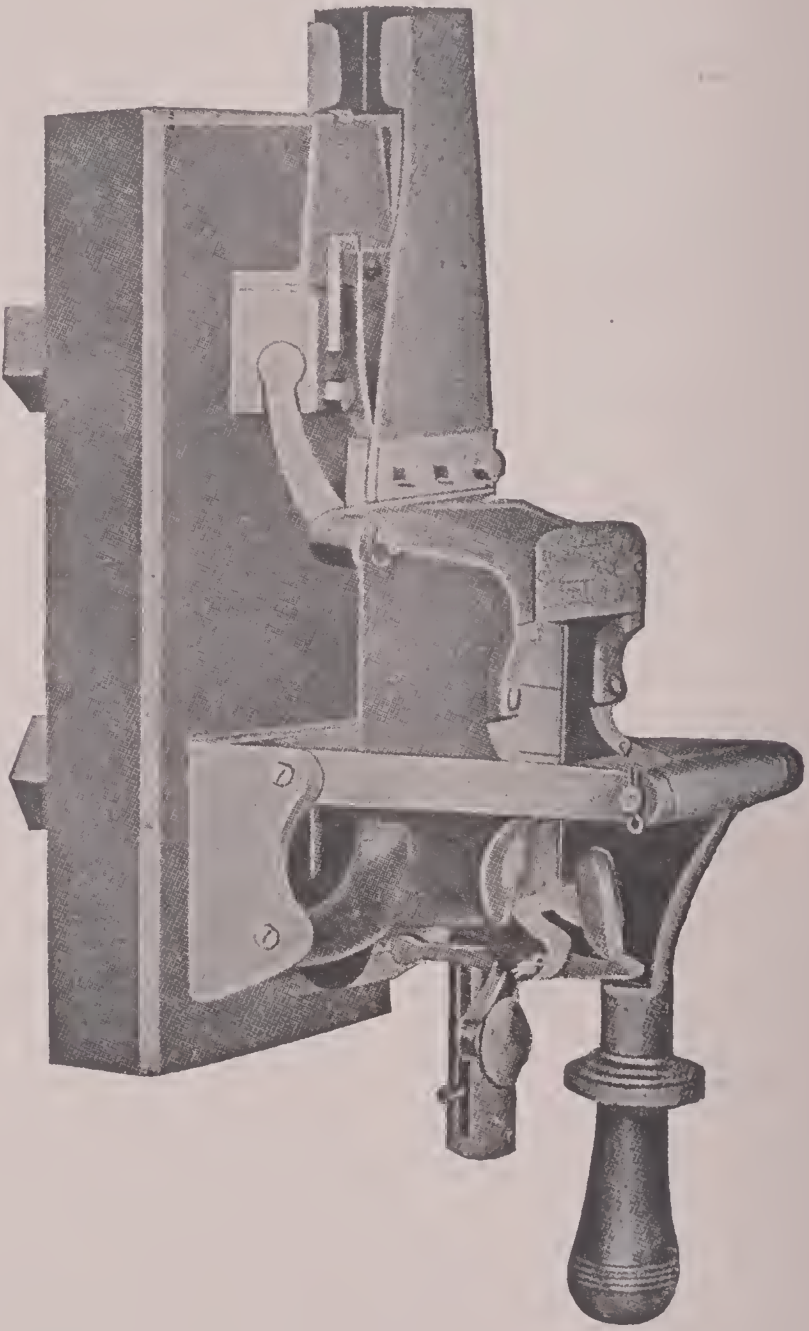

Fig. 164. Carbon Break Circuit Breaker, 150 to 800 Ampere Capacity.

The weight of rod and core of armature would be sufficient so that the lifting power of the solenoid was not great enough to lift them, but that 1000 amperes through the solenoid will lift the rod and release the catch. The spring then opens the breaker. When a circuit is to be opened the attendants push up the rod and thus open the breaker.

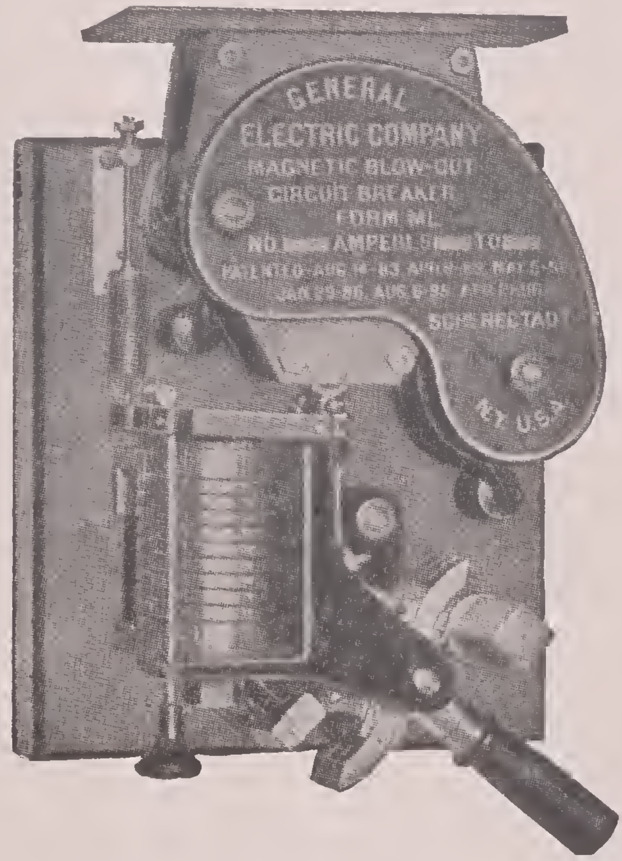

Fig. 165. Magnetic Blow-out Breaker. Small Capacity.

When this is done it is called tripping the breaker, when the breaker is tripped by the action of the current it is customary to say the breaker has "blown."

Whether a breaker is tripped or blown, it makes a noise like a pistol shot. The larger the current blown, the greater the noise.

The tripping solenoid is shown plainly in Fig. 165.

If large currents are handled by the breaker a solenoid of one-half a turn may create enough power to trip the breaker.

In Figs. 163 and 164 this is the case, and the tripping device is not in evidence.

If the rod and its attachments were heavier it might take 1200 amperes to trip the breaker; if the core or armature were moved nearer or further from the solenoid, a smaller or larger current would trip the breaker; if a more or less strong spring were attached the current required to blow the breaker would vary with the tension of the spring.

These devices are used to set the current at which the breaker will operate.

Breakers are made to have a capacity for certain currents continuously passing through them without over heating. This is called their Continuous Capacity.

The carbon contacts are then designed to break a current of from 50% to 100% in excess of this current for several hundred times without needing renewal of parts. This is called the maximum capacity.

Sometimes the maximum capacity is two or three times the continuous capacity. Such breakers must be very heavily and strongly built, and are much higher in price.

The lowest current at which the breaker can be set to operate is called its minimum calibration.

In Fig. 163 at the left side is a rod screwed in an arm. The lower end of this rod has a flange which holds an armature from falling down, but does not prevent its rising.

The upper end of the rod moves past a scale marked in amperes. Turning this rod till its head is opposite a certain number draws the armature into such a position that the indicated number of amperes will pull the armature up and release the catch or trigger, which can be plainly seen holding the arm which operates the toggles in place.

It is evident that the scale reads from the top down, for then setting screw at smallest number brings the armature nearest the solenoid. Fig. 165 shows the armature above the solenoid with a spring to change the pull required to draw it down and release the trigger.

In this breaker the main contacts are between the handle and the solenoid, while the secondary contacts are up top behind the name plate.

In Fig. 166 is shown a breaker with a core in the solenoid.

The main current circulates around the solenoidal coil "B" and tends to draw into the solenoid the movable plunger "C." The initial position of this plunger in the solenoid is determined by the adjusting screw "M." When the current is sufficient to overcome the weight of the plunger it is drawn into the coil with constantly increasing velocity, due to intensified magnetic action, as the polar distances or air space is decreased. When nearing the upward limit of its travel, having acquired a high momentum, it impinges upon the trigger "N" through the medium of the push pin "E." The immediate result of this is the release of the switch arm by the displacement of the retaining catch "F." The upper projection "H" of the trigger "N" is thrust against the striker plate "K," thereby utilizing the energy of the current to start the movement of the switch arm. This movement is intensified and sustained beyond the point of final rupture between the switch contacts by the thrust of the spring "O," which is released from compression by the initial action of the trigger. Thus the contact arm is thrown away from the contact terminal, and the circuit is opened.

As the screw "M" is turned up and locked by "T" it prevents the core "C" from falling away from the solenoid. The higher "C" the lower the current at which breaker blows.

The fact that the current is broken between the carbon blocks tends to suppress the arc formed, and in the breakers shown in Figs. 163, 164, and 166 this is alone relied on to kill the arc.

It must be remembered that although these breakers have two contact blocks at the main copper contact, yet only one wire of the circuit is attached to the breaker. The current enters at one block, goes over the copper brush to the other and out to the line. The carbon contacts are a shunt. Circuit breakers are adapted to different voltages by the excellence of the insulation and by the length of the openings between contact pieces.

The breakers shown are all suitable for D C and A C circuits of 100 to 800 volts.

The breakers shown in Figs. 161 and 165 have a magnetic blowout; that is, a solenoid is situated at the carbon contact, which actually blows the arc out the same as in the Thomson lightning arrester.

The breaker in Fig. 161 has two attachments which are of great service. These are the Low Voltage Release and the Tell Tale.

The way these act is best explained in connection with Fig. 167.

The Low Voltage Release is a coil of low resistance

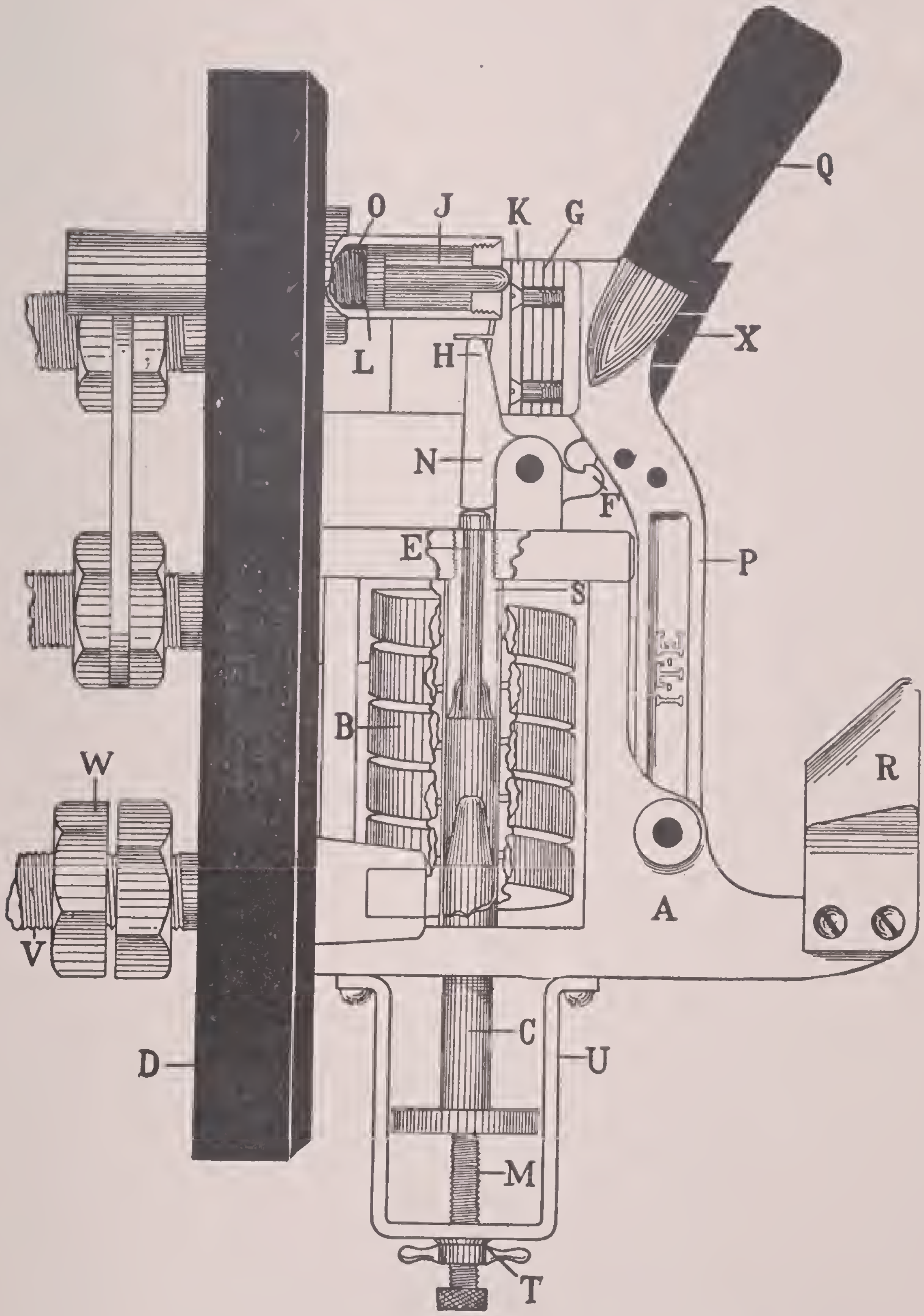

Fig. 166. Cross Section of Circuit Breaker.

holding by its armature the trigger of the breaker. A resistance is placed in series with this coil and both together are placed as a shunt across the line. In the diagram one side of the release coil is connected to ground, which is negative, and the other side through the series resistance to the positive brush of rotary converter.

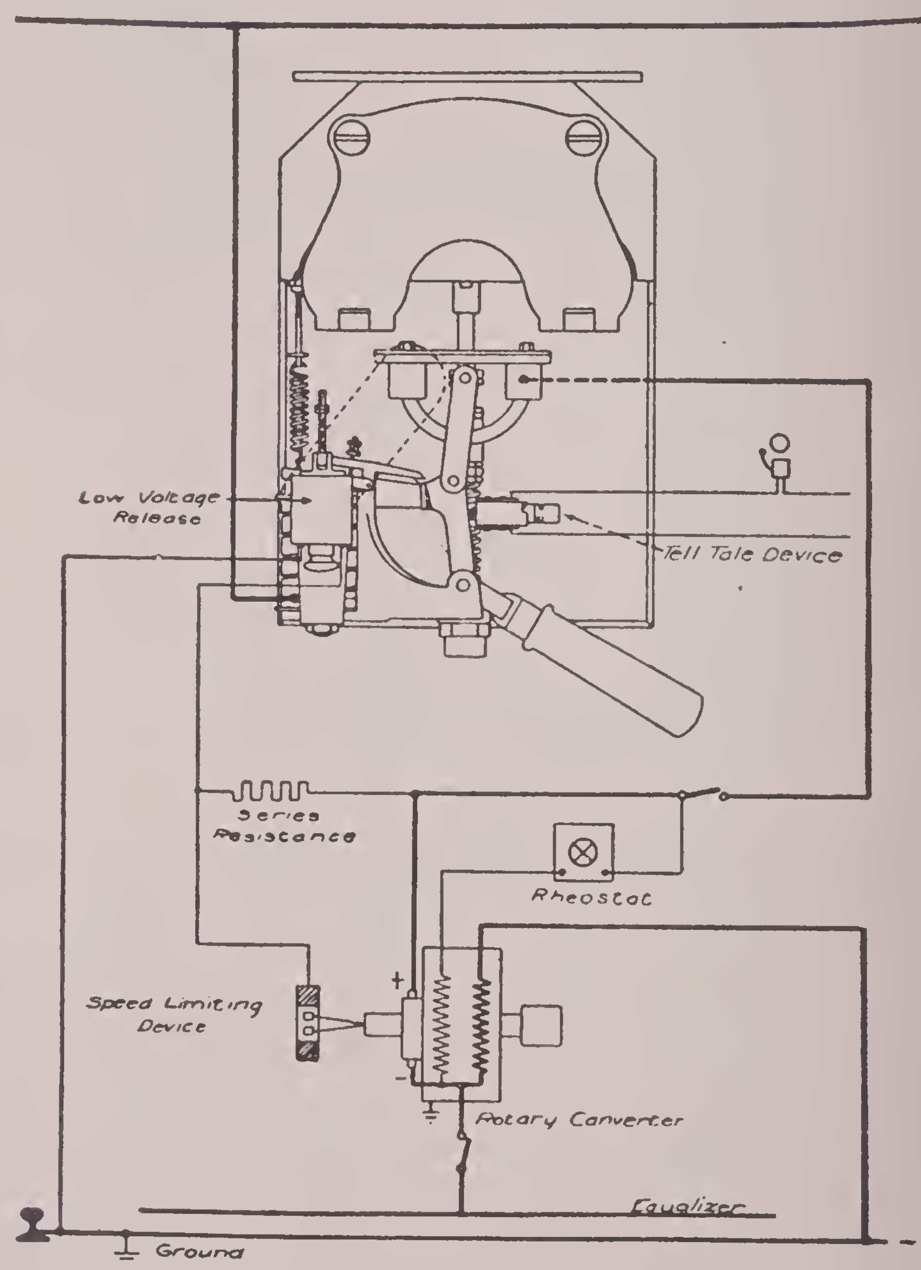

Fig. 167. Electrical Connections of Fig. 161.

As long as the voltage is normal this coil is a strong enough magnet to hold the breaker trigger set, although at any time the main solenoid can release the trigger independently of the low voltage coil.

If the voltage falls to half the normal pressure the coil becomes such a weak magnet that the trigger is released and breaker opens.

Wires are often run from the terminals of the low voltage coil to push button in different parts of the station.

Pushing the button then forms a short circuit across the low voltage coil and robs it of its current. It ceases to be a magnet and the trigger is released. The breaker can thus be opened from several distant points.

To prevent rotary converters from racing at great speed, when power on A C side is suddenly thrown off, there is a speed limit device on the rotary which consists of a ring in which a fly-ball governor rotates. The ring is connected to one side of the low voltage coil and the fly-balls through the negative wiring, to the other side. When the rotary goes too fast the fly-balls open out and touch the ring, completing a short circuit across the low voltage coil and thereby releasing the trigger.

The Tell Tale is merely a mechanically operated switch, which the opening of the breaker closes. The tell tale may close the circuit of an electric bell and call the attendant's attention.

It usually rings a bell and lights a lamp. It may even trip a second breaker, if it is desired to always have the two "go out"* at the same time.

For higher voltages, 6600 volts and upwards, break-

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*Another expression for "blowing."

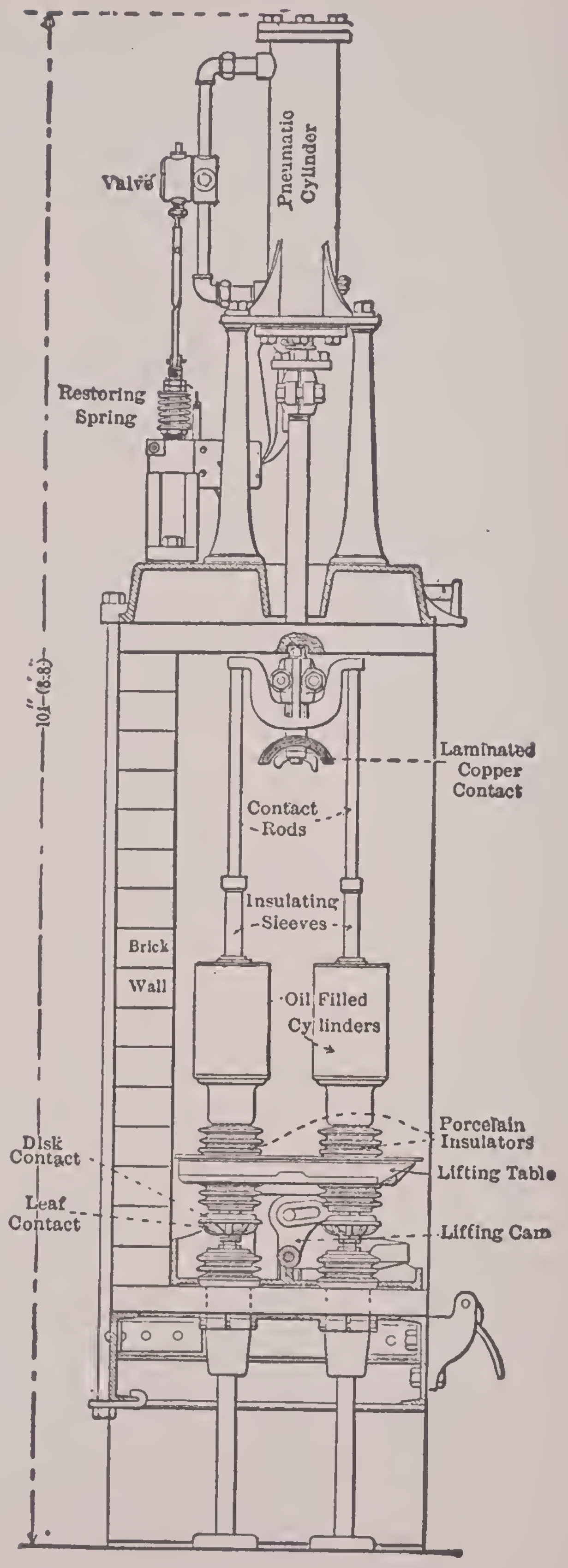

Fig. 168. Oil Circuit Breaker.

ers of type shown in Fig. 168 are used. A magnet when current is too large operates the valve which admits air to the cylinder. The cylinder piston through a wooden rod operates the main contact first and then the secondary contacts which are enclosed in oil filled cylinders.

LESSON 22.

Direct and Alternating Current.

We have seen that when direct current, as it is called, passes through an electro-plating bath, there is a transfer of chemicals in both directions. The metals go from the anode to the cathode, i. e. from + to — negative wire. The non-metals such as sulphur, chlorine, etc., are transferred from the cathode to the anode.

It seems as if direct current flowed in both directions around the circuit, but since the metals are of the most importance to us we speak and often think of direct current as flowing only in one direction.

The test for direct current is that it will electro-plate.

Ohms Law in its simple forms as mentioned in Lesson 19, applies absolutely to direct current.

It is a fact that for the first fraction of a second after a switch is closed the current is growing to the value it ought to have as given by Ohms law.

This growth is very rapid when the circuit contains no coils or magnets. These retard the rise of the current.

The current in the field circuit of a dynamo may take 3 seconds to attain its full value, but once there its value is given by Ohms Law.

Alternating Current.

An alternating current will not electro-plate, for the metal-plating part of the current reverses direction many times a second.

An alternating current will not deflect a magnetic needle because the deflecting impulse reverses its direction continually.

Alternating current can excite a magnet causing a core to be sucked into a solenoid or an armature to be attracted, because induced magnetism in core changes with the polarity of magnet itself.

Alternating current measuring instruments do not contain magnetic needles, but are supplied with two coils. The magnetic action between these two coils is just as strong as if direct current were used, because the A. C. reversing in each coil at the same time keeps the relative polarities the same.

Other A. C. instruments like the Thomson Ammeter Fig. 157, exert a magnetic action on a vane. This vane is not itself a magnet.

Since A. C. does not electro-plate the original definition of an ampere is of no use here, but since the heating done by electricity is the same for equal quantities whether A. C. or D. C. we define thus:

An ampere of A. C. is that current which produces as much heat per second as one ampere of D. C.

For example: A car heater raises the temperature of the car from 60° Fah. to 70° in half an hour. The ammeter read 20 amperes D. C. If A. C. were supplied and raised the temperature from 70° to 80° in the next half hour we would say that 20 amperes A. C. were flowing.

Ohms Law applies to A. C. when written thus:

$$C=\frac{\text{Impedance}}{\text{Volts}}$$

The *impedance* is larger than the resistance of the circuit, it being the result of the resistance and the reactance.

Resistance is the opposition offered by a conductor to any or all current passing.

Reactance is the extra opposition offered by a conductor to a current which is changing in value. It depends on the rapidity of this change and on the number of coils of wire in the circuit. It is measured in ohms and is calculated by the formula:

$$\text{Reactance} = 6.28 \times f \times L$$

where f=frequency

L=coefficient of Self-induction.

The frequency, as explained before, is the number of times the current reverses per second. It runs from 25 in power and railroad work up to 133 in electric lighting. It is best determined by taking the speed of the alternator in the power house and counting the number of pairs of poles that alternator has.

Calculating the number of pairs of poles passed a second gives the frequency.

Problem: An alternator makes 75 revolutions per minute and has 40 poles; what is the frequency of the current delivered?

40 poles=20 pairs poles

75 r. p. m.=1.25 r. p. second

$20 \times 1.25 = 25$ pairs poles per second.

25=frequency.

Self Induction.

When the current changes strength in a long straight wire the resistance of the wire does not resist the change. for the resistance offers the same opposition to any or all currents; it is the magnetic field around the wire which causes the *reactance* of the wire.

Every current has its definite magnetic field in the air around the wire and when current is increased the magnetic field has to increase to its new value. When the current alternates the rapid dying away and regrowth of the magnetism consumes some of the power so that for the same E. M. F. the current is less when it is A. C. than when D. C.

The greater the frequency the greater is the reactance of the circuit because the more frequent the rise and fall of the magnetic field about the wire.

Perhaps it would be truer to facts to say that the rise and fall of the magnetism causes it to cut through the wire and produce an E. M. F. opposite to that produced by the alternator which reduces the net E. M. F. impressed on line.

When coils of wire are present this action is much stronger because the magnetism cuts the circuit oftener on each rise and fall.

The action of the coils is called Self-Induction and the number representing the action is called *henrys,* named after Henry, a noted electrician.

It is well to remember that the reactance of the circuit is caused by the frequency of the A. C. and the self-induction of the circuit.

Problem: Suppose a circuit of 0.12 henrys self-induction and 184 ohms resistance conducts A. C. at a frequency of 60. What will be the current flowing with 11000 volts

$$\begin{aligned} \text{Reactance} &= 6.28 \times f \times L \\ &= 6.28 \times 60 \times 0.12 \\ &= 45 \text{ ohms} \\ \text{Resistance} &= 84 \text{ ohms} \end{aligned}$$

Impedance=Square root of the sum of squares of resistance and reactance.

Resistance squared=7056 ohms
Reactance squared=$\underline{2025}$
Sum of squares=9081
Square root=95.3
Impedance=95.3 ohms.

$$C = \frac{\text{Volts}}{\text{Impedance}} = \frac{11000}{95.3} = 115.4 \text{ amperes.}$$

Capacity.

The presence of condenser action or capacity in a A. C. circuit is a help because all circuits have some inductance (self-induction plus the effect of any circuits near the one in question), and the capacity tends to neutralize this, bringing the value of the impedance nearer to the resistance.

It is even possible to artificially make the capacity so great that the impedance is practically equal to the resistance.

Such a circuit would conduct A. C. or D. C. equally well.

Lagging, Leading Currents.

If a shunt is put in a circuit and an ammeter connected to it, while a voltmeter is connected to the same part of the circuit, if* readings could be taken of the values of current and voltage at any instant of time we would find that the highest value of voltage and current did not appear at the same time.

We would see that the value of the current as given by C=Volts÷Impedance, occurs a fraction of a second after the voltage causing the current has passed. We say the current lags behind the voltage. If we add more inductance to the circuit the current will lag more and more until it seems to the observer at an oscilligraph that the current can hardly belong to the voltage he is watching, because the largest current is flowing when the voltage is almost down to zero and positive current is flowing when the voltage has reversed and is negative.

If capacity is now connected to the circuit the current will move up to a position nearer where it naturally should be until with sufficient capacity it will follow exactly the changes in the voltage. That is the highest current and voltage will occur at exact instant.

Add more capacity and remove all inductance possible by taking out of circuit all coils or machinery containing coils, especially if they have iron cores.

The current will actually lead the voltage. That is, the highest current will flow a fraction of a second before the highest voltage occurs.

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*An instrument called an oscilligraph can make these instantaneous readings.

Power Factor, Wattless Current.

The power in this circuit while all these changes have been going on has varied greatly. When the current and voltage were together the power was the greatest, when the current either led or lagged the power was less. This is because the power is determined by multiplying the current and voltage which occur at the same time. It makes no difference whether that voltage belongs to that current or not. It is the product of the things which are happening at the same time which gives the power.

If an A. C. ammeter and voltmeter are put in circuit each instrument reads the average current or voltage irrespective of the time at which these currents or voltages occurred. Multiply these two readings and you get the power produced by the current and the voltage which belongs to it. If you should now place a wattmeter in the circuit it will measure the actual power, i. e. the average of current multiplied by the voltage which occurs at the same instant.

This wattmeter reading is the actual power. The ammeter reading multiplied by voltmeter reading gives the apparent power.

The decimal number by which the apparent power must be multiplied to get true power is called the Power Factor.

If a current of 250 amperes is flowing at a pressure of 1000 volts we have an apparent power of 250000 watt or 250 K. W. If the true power as read by the wattmeter is 200 K. W. the power factor must be 0.8 for $250 \times 0.8 = 200$.

$$\text{Power Factor} = \frac{\text{True power}}{\text{Apparent power}}$$

$$= \frac{\text{Wattmeter reading}}{\text{Volts} \times \text{amperes}}$$

By saying that the prèssure measurement is correct we throw the blame on the current and say that all the current which flows, say 250 amperes at 1000 volts, is measured by the ammeter, while only the current which works or produces watts is taken into consideration by the wattmeter. According to this idea the wattmeter would only notice 250×0.8=200 amperes. The other 50 amperes are called the wattless or idle current.

It is customary to speak of A. C. waves. This is quite natural for the rise and fall of voltage and current in an A. C. circuit reminds one of the waves in a long string which is shaken to and fro at one end while being held fast at the other.

LESSON 23.

TRANSFORMING DIRECT OR ALTERNATING CURRENT.

Direct Current.

Perhaps one of the greatest objections to the use of direct current is the inability to change its voltage without the use of moving machinery.

There is but one way to transform D. C. and that is by a motor and generator.

This motor-generator set usually consists of a D. C. motor driven by current at the pressure of the incoming line. This motor drives a D. C. generator which furnishes current at the desired pressure.

By altering the strength of the field of the generator we regulate the outgoing pressure to suit the requirements.

The motor and generator are built on the same shaft and set on a long cast iron base, making them mechanically one machine.

When the incoming and outgoing voltages can have the same ratio to each other always, a cheaper form of machine can be used called a Dynamotor.

This is a D. C. motor running on the incoming voltages. On the same armature core is a separate winding connected to its own commutator at the other end of armature. The one set of field magnets serves for the motor winding and the generator or dynamo winding.

This inability to transform cheaply seems to be a great disadvantage, but as we so seldom want to do it the inability to do so does not bother us much.

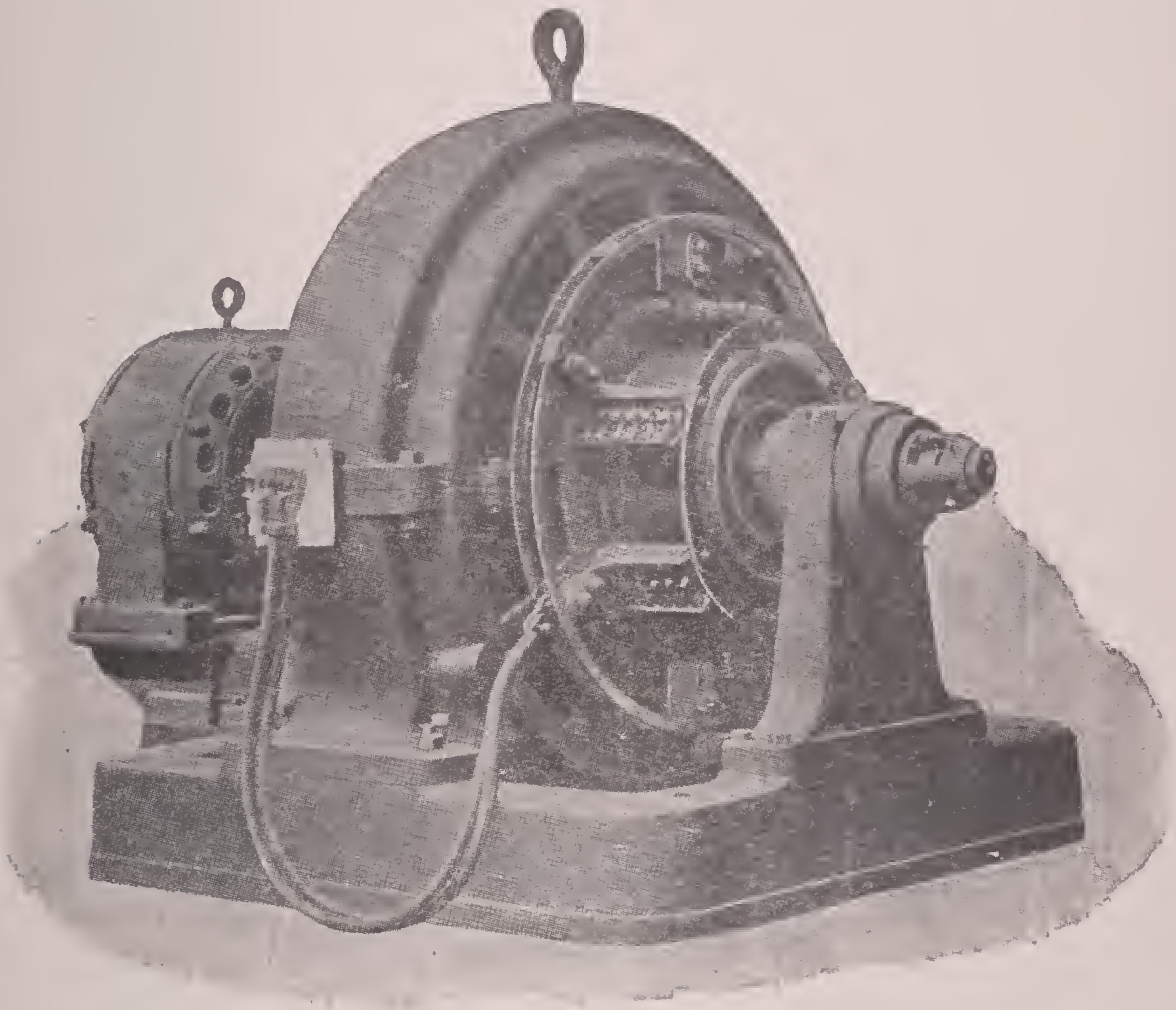

Fig. 169. 500 K. W. 3 Phase Rotary. 460 A. C. Volts to 660 D. C. Volts. Frequency 25. Commutator End.

In railroad work when we wish to charge storage batteries from 600 volts circuits we use a motor-generator.

Alternating to Direct Current.

Many D. C. traction systems transmit their power by A. C. Thus we need to transform A. C. to D. C. and we do so by a certain form of dynamotor called a *Rotary Converter* or a *Rotary.*

The New York Central has a dozen large ones in its sub-stations; the Interborough Rapid Transit Co. of New York has 83 of moderate size.

A rotary looks like a dynamotor but has a collector or slip rings like an alternator at one end and the regular commutator at the other.

They often have small motors fitted on the same base to start them up. After being once started they run all right.

Fig. 169 shows the D. C. or output end and Fig. 170 shows the A. C. or intake end of a rotary, the starting motor being clearly shown in each figure.

There is only one winding on the armature core, both commutator and collector are connected to it.

The reason the A. C. does not pass through machine to the D. C. lines is because the commutator rectifies the A. C., i. e., lets through all the + part unchanged and reverses all the — part as it lets it out to the D. C. circuit.

The average pressure of an A. C. is of course less than its highest pressure, and voltmeters read the average. It is the greatest pressure however which gives the pressure to the D. C. end of rotary. It is due to this that a 460 volt A. C. will produce by means of a rotary a 660 volt D. C.

A rotary looks smaller than a generator of equal power and this is so. The rotary does very little work, so it need not be made very heavy and strong.

Rotaries have a tendency to shift in speed running fast and slow; this is called "hunting." It is prevented by heavy copper straps around the ends of the field poles and bars of copper laid in slots of the pole piece.

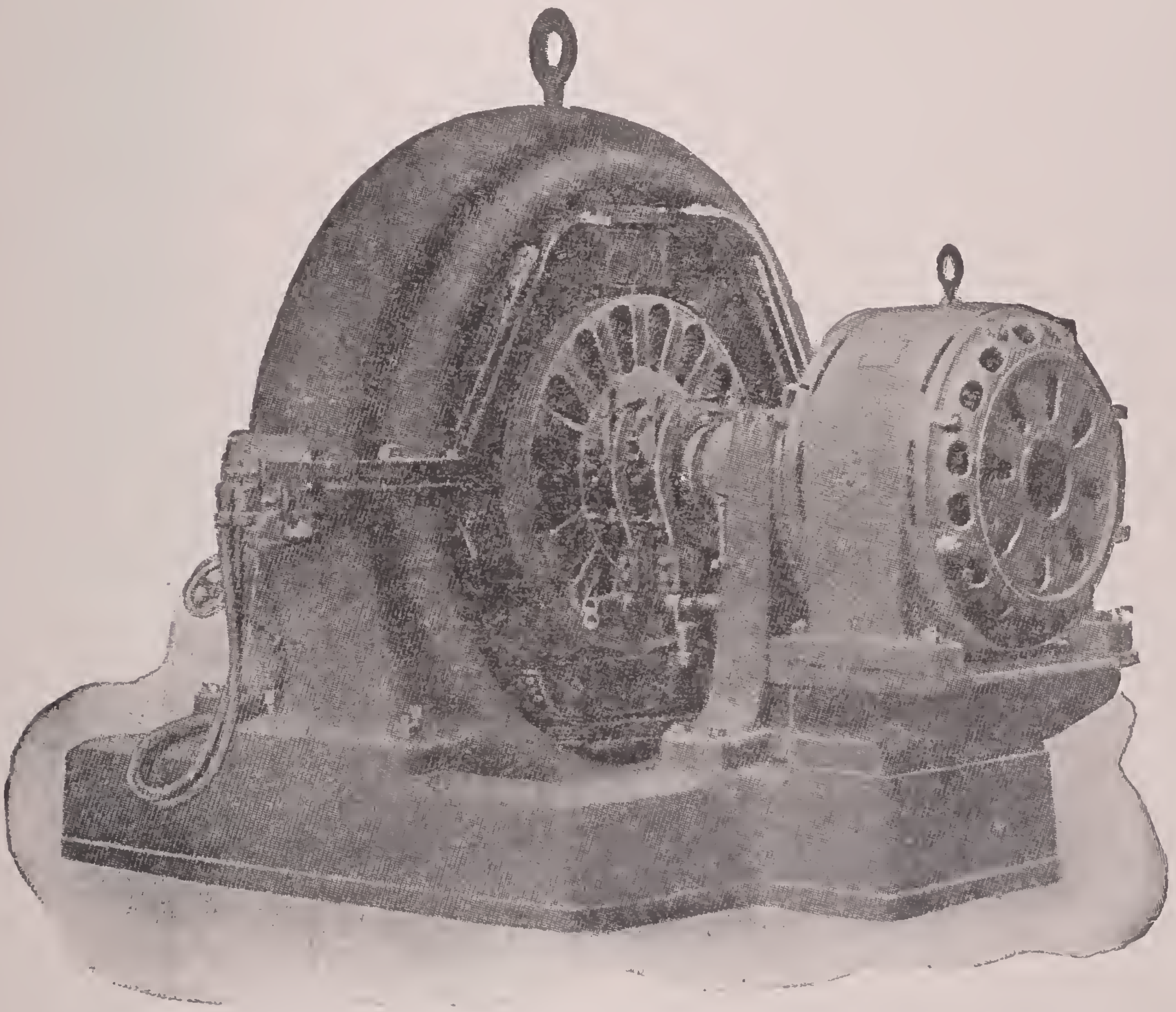

Fig. 170. Collector End of Rotary Shown in Fig. 169. Motor for Starting at Right-hand End of Base Plate.

These copper strips have eddy currents in them each time the speed changes, and the effect of these eddy currents on the armature is to bring it back to normal speed.

Alternating current motors can be built to start themselves like D. C. motors, but rotaries are often started by motors or from their own D. C. ends as direct current motors. In this latter case the A. C. line is thrown on when machine is up to speed. The A. C. then begins to run machine and D. C. power is delivered from the commutator *A. C.*

The transformation of A. C. is the simplest operation in electrical engineering. No moving machinery is needed. The same principles which govern the action of an induction or medical coil operate a transformer.

Electro-Magnetic Induction.

When a dead or idle circuit is approached by a magnet there is a current induced in the idle circuit.

Even should the magnet remain stationary if its strength changes a current is generated in the idle circuit.

The complete set of facts is:

If a dead and loaded circuit approach each other;

If the current in loaded circuit increases;

Then a current is induced in the dead circuit in the opposite direction to the current in loaded circuit.

If a dead and loaded circuit recede from each other;

If the current in the loaded circuit decreases;

Then a current is induced in the direction of the dead circuit in same direction as current in loaded circuit.

As long as the motion or the change of current lasts, so long will the induced current last, and no longer.

Furthermore the ratio of the pressures in the loaded and now alive circuit will be the same as the number of turns of wire in the two coils which are acting on each other.

If in Fig. 171 A represents the alternator, B its brushes and D and E the mains to the transformer H. This transformer consists of a core of iron C on which are two windings. The coil P is called the primary and is connected to the main from alternator. The other coil S is called the secondary and to it the load is connected.

Whatever the voltage of alternator A that of the secondary circuit F. L. G. will be three-eighths of it because there are 8 turns on primary and 3 turns on secondary. The power in the secondary circuit is practically the same (minus the losses) as is given out by alternator, hence the primary current is low and wire is small. The secondary current is large so wire is large.

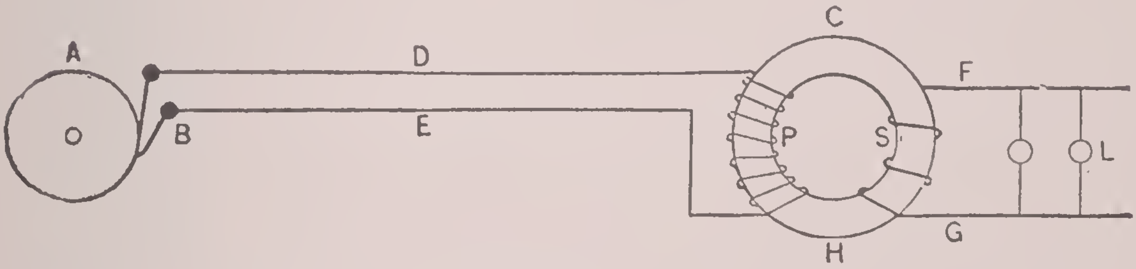

Fig. 171. Diagram of Alternator, Line, Transformer, and Secondary Circuit.

Since one kilowatt can be a combination of a large current and small pressure or small current and large pressure, it is evident that the transformer simply transfers the power, and transforms the voltage and indirectly the current.

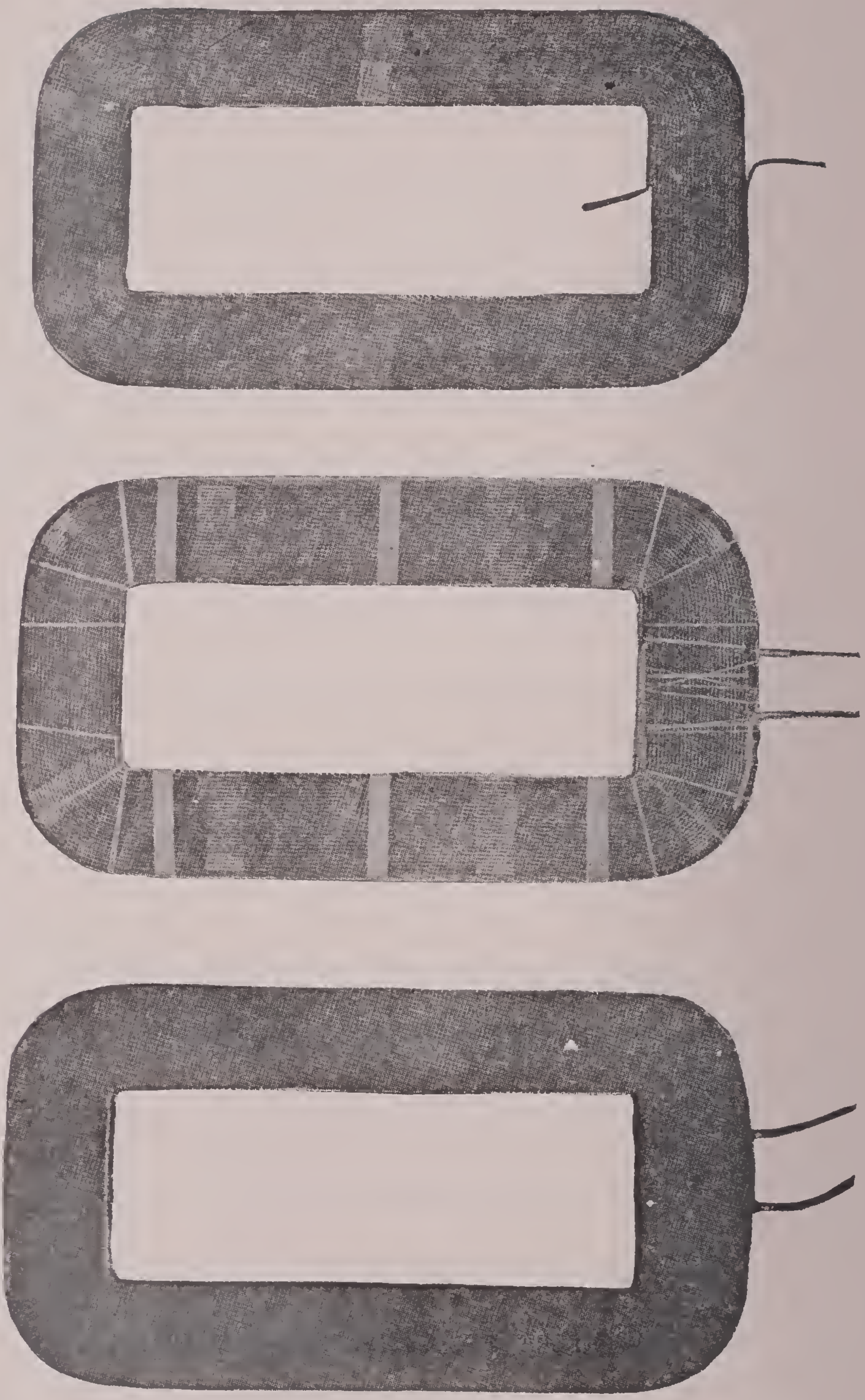

Fig. 172. Transformer Coils in Wound, Bound and Taped Stages of Completion.

Remembering the power formulas in this way $W=Ec$ or eC helps one to grasp the action of transformer.

This transformer (Fig. 171) lowers the voltage and is called a step down transformer.

When the secondary is connected to the alternator the transformer raises the voltage and is called a step up transformer.

The coils of a transformer must be very well insulated. After winding they are bound to keep them in shape and then wound with linen tape or varnished cambric cloth. Fig. 172 shows a coil in the three stages of completion.

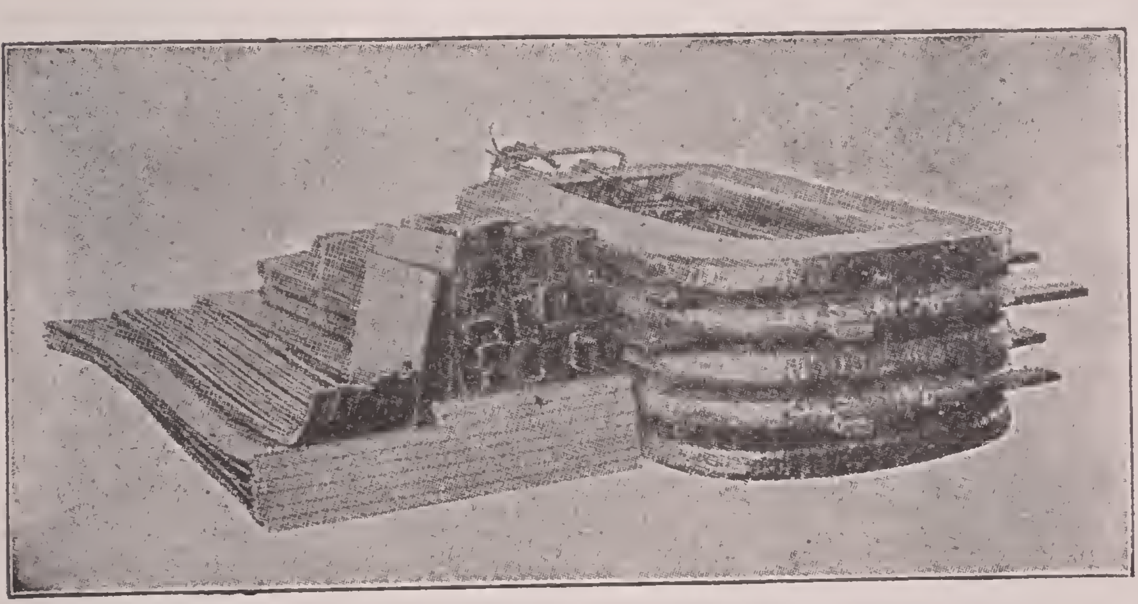

Fig. 173. Coils, Air Ducts, and Separators for Transformer.

In Fig. 173 is shown a set of completed coils, together with the ventilating ducts and mica barriers sufficient for one leg of a transformer.

Fig. 174 shows the two legs of a transformer, which form its iron core, each over half-filled with coils. The coil is made of sheets of soft iron.

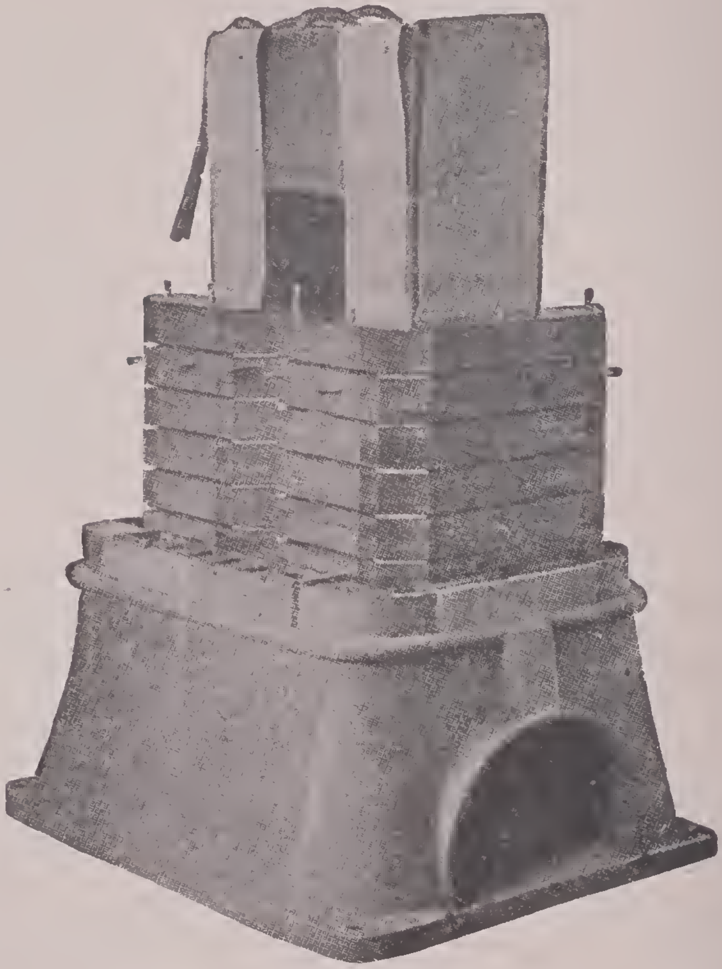

Fig. 174. Interior Construction of an Air Blast Transformer.

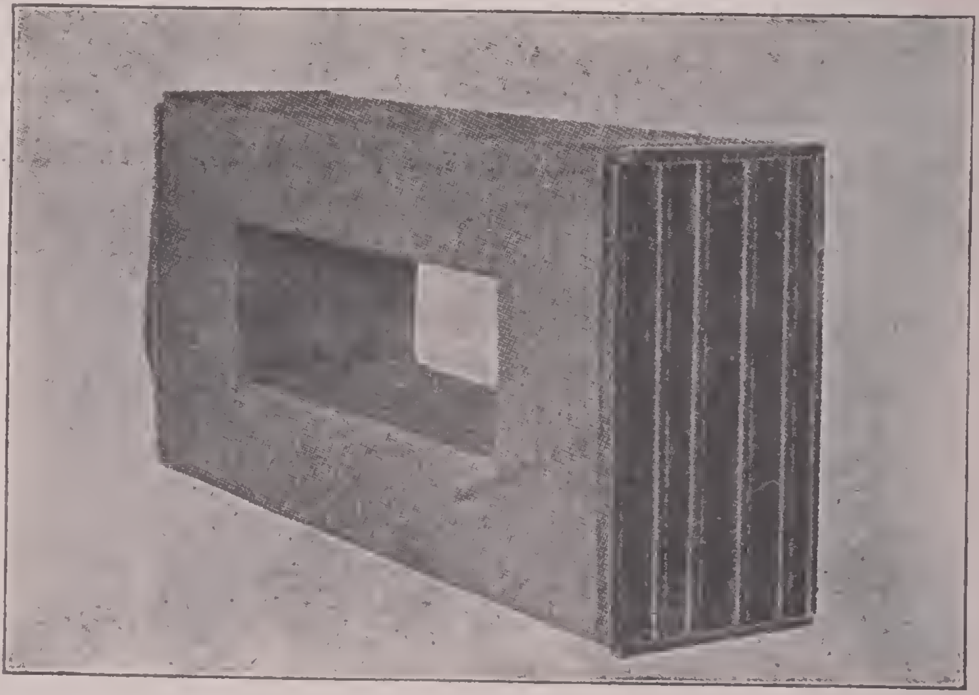

Fig. 175. Set of Coils Made up Ready to Be Placed in Transformer

Fig. 175 shows the manner in which sets of coils are sometimes bound up to be placed in transformer as one coil.

Exciting Current.

The Exciting Current being also called by various other names, such as leakage current, open circuit current, and magnetizing current, is a very important thing.

In order that a transformer may be ready to do its work it is always connected to the line. This means that the primary coil is always magnetizing the core if no current is drawn from the secondary.

This steady flow of current to excite the primary is the price we have to pay for having the transformer continually ready for service.

A transformer should therefore never be left on a line unless it is needed.

Efficiency of Transformers.

The losses in transformers are less than any other piece of electrical machinery or apparatus; 98% of the intake being delivered in the larger sizes as used in railroad sub-stations or power houses, when fully loaded. Unfortunately they lose about the same amount of power at all loads.

A 100 K. W. transformer loses 2 K. W. at full load, its efficiency is then 98÷100=0.98. At half load it loses 2 K. W. but is only carrying 50 K. W. so (its losses are now equivalent to 4 K. W. on a 100 K. W.) its efficiency is 48÷50=0.96.

At quarter load it takes in 25 K. W., loses 2 K. W., so its efficiency is 23÷25=0.92.

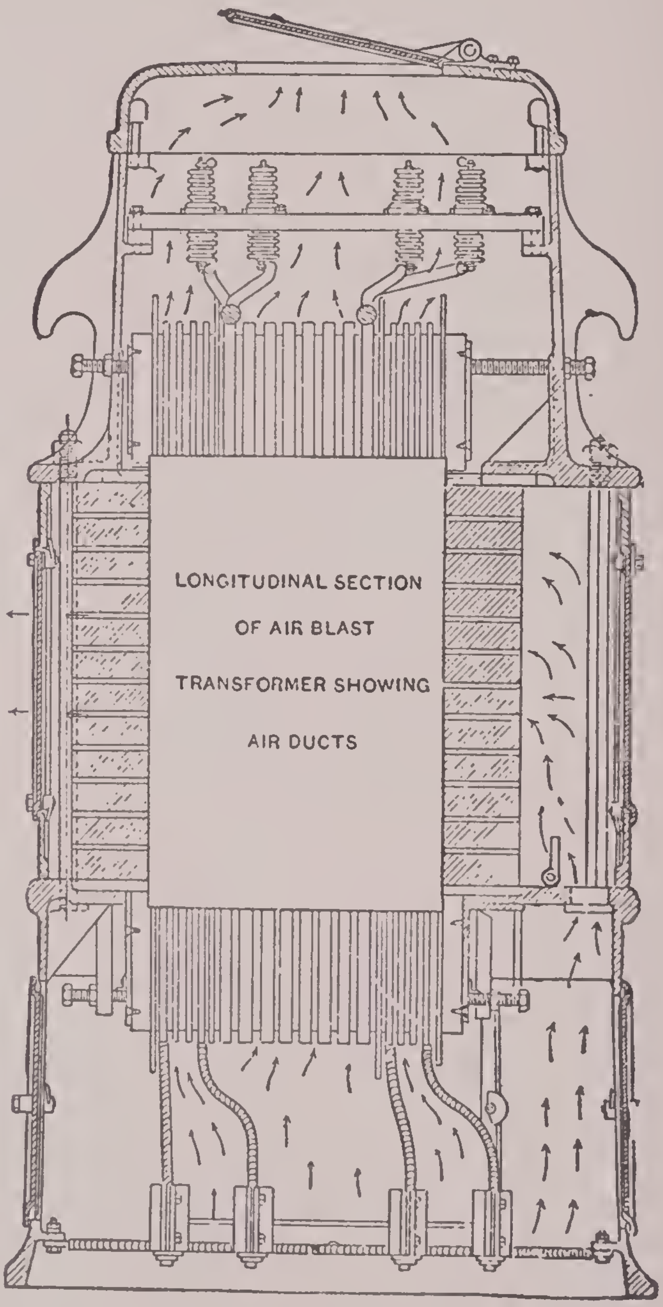

Fig. 176. Air Blast Transformer.

By clever designing transformers are built to be most efficient at three-quarters load. They are a little less efficient at half and full loads, and still less at quarter load and quarter overload, but never fall below 95%.

Cooling Transformers.

Small transformers hung up on poles are cooled by surface radiation only.

Medium sized ones are filled with oil. This conducts the heat to the iron case and also acts as an insulator.

The oil will also flow in and fill a break in the cloth or mica after a puncture.

Air blast avoids the danger of oil in case of fire or flame due to short circuits. They are cheap as a transformer may be much more heavily loaded when cooled by the air blast, and the blower only consumes 1/10 of 1% of the full load output of transformer.

Fig. 176 shows the interior construction of an air blast transformer and Fig. 177 shows how they are installed.

Water Cooled. These are the smallest and cheapest transformers to build but not so cheap to run as the air blast.

The cases are filled with oil which absorbs heat from coil. Pipes are run through the oil, in which cold water is circulated.

In a water power plant where the head of water would render pumps unnecessary the water cooled type would certainly be the best.

Auto-Transformers.

These are only applicable to certain cases.

The idea is shown in Fig. 178. The same coil of wire A to B is used as primary and secondary, the whole

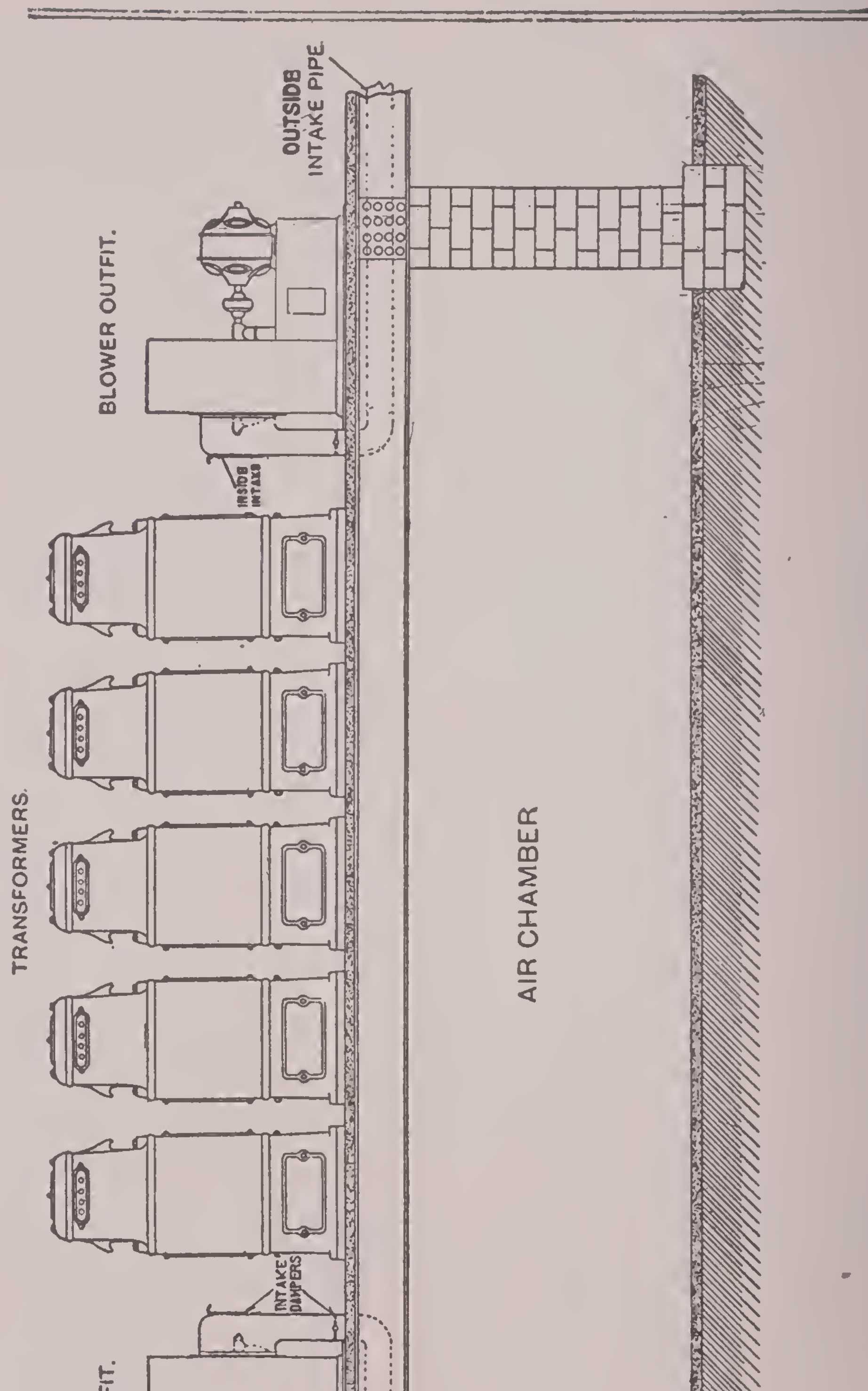

Fig. 177. Installation of Air Blast Transformers.

being the primary and portions as C to D, D to E, or C to E being used as a secondary.

They are only used where the primary voltage is fairly low and the secondary voltage is not less than one-fifth of the primary voltage.

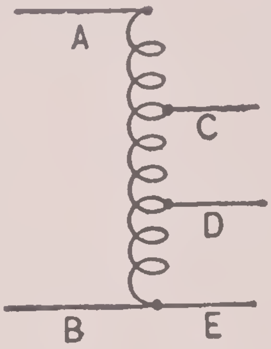

Fig. 178. Diagram of Auto-Transformer or Compensator.

They are used instead of resistances to start A. C. motors.

LESSON 24.

THE DYNAMO.

The dynamo is a machine for transforming mechanical energy into electrical energy, by use of the principles of electro-magnetic induction. These principles were discovered by Faraday. You may repeat his experiments for yourself.

Direction of the Induced E. M. F. In front of you on the table lay a magnet with its N-end projecting over the edge. Take a copper wire and connect its two ends to a galvanometer or pressure meter; usually called a *Voltmeter.* Stretch a portion of this wire between the right and left hands, and move the wire rapidly down in front of the N-end of the magnet at right angles to lines of its action. There will be induced in the wire a pressure or *Electro-motive force* which will send current through the wire from your right hand to your left. The galvanometer will give a deflection showing the flow of current.

This deflection is not a permanent one, the needle instantly dropping back to zero, proving that only a momentary current was produced.

If the experiment is tried moving the wire upwards the direction of the momentary circuit is reversed.

With a downward motion in front of a S-pole we get a left to right current.

Hence, starting with a certain polarity and direction of motion, changing one changes the direction of the induced current, while changing both the polarity and the direction of the motion does not reverse the current.

Now hold the wire a foot away from the magnet and directly opposite it, moving the wire up to the magnet and back again, keeping the distance from the wire to the floor the same, so that the motion shall be parallel to the flux. No E. M. F. is generated in this case.

An electromagnet would do as well and probably better as they are usually stronger than permanent magnets.

The value of the Induced E. M. F. depends on the following:—

1. The greater the strength of the magnet the greater the E. M. F.

2. The more rapidly the wire is moved, the greater the induction.

3. The larger the number of turns in a coil of wire the greater is the E. M. F. induced in it.

The induced E. M. F. therefore depends on the *flux,* the *speed of cutting* this flux, and the *number of wires* cutting this flux.

A dynamo reduced to its simplest form is a coil of wire arranged so as to cut the magnetic flux of an electro magnet, thus producing an induced electromotive force.

A dynamo therefore does not generate electricity, but pumps up a pressure as does a water pump, thus causing the electricity to flow through the circuit, which is called a current.

The current flows through the dynamo and the external circuit in *series,* hence the greater the current the larger must be the dynamo and the heavier the wires of the external circuit.

Since the E. M. F. (electromotive force) can be produced almost entirely by speed of the machine, the voltage at which the current is delivered does not affect the weight of the machine very much.

It is also evident that the faster a machine is driven the smaller the magnets can be and yet the same E. M. F. be produced. This is why high speed generators weigh less than low speed machines. The usual 600 volt railway generator weighs 11, 13, or 16 pounds per ampere of current capacity.

The railway generator whose voltage is 600 and whose resistance is 0.025 of an ohm, would give a current which can be calculated by Ohms law.

$$\text{Amperes} = \frac{\text{E. M. F.}}{\text{Resistance of generator plus resistance of the external circuit.}}$$

If we allowed the external resistance to fall too low by attempting to operate too many locomotives at the same time, the current drawn would generate a great amount of heat while passing through the machine. The amount of this heat can be calculated by the rule.

Heat in Watts is equal to the Square of the current multiplied by the resistance of the generator.

If we build an 11-ton generator and load it too heavily, that is, put 4000 amperes on it; it will have C^2R

watts of heat or 16,000,000 x 0.025 equal to 40 K. W. (kilo watts) to dissipate. Now a machine like this has such a small surface that it cannot radiate 40 K. W. of heat to the air, whereas if a heavier machine had been built, one of 22 tons, it could have gotten rid of the heat. Moreover the copper wires of the 22-ton machine being larger than those of the light machine, the resistance they offer is less, and there will be less heat generated. Thus the heavier machine will run cooler than even the light machine properly loaded.

The danger in overheating of generators is the damage done to the cotton insulation of the wires, due to scorching, and the melting of the shellac varnish between the layers of mica. The mica itself stands the heat very nicely. Any overheating of the armature and the commutator is at once conducted to the bearings.

To prevent the generation and retention of too much heat it is customary to allow 700 C. M. (circular mils) of copper for each ampere of current and to design the shape of the coils of wire so that they will have one square inch of surface for every two watts of heat to be gotten rid of.

The generator must be protected by fuses (which will melt) or by circuit breakers (automatic switches opening at a definite current) which will open the circuit and prevent the further flow of current in case of an accidental low resistance or *short circuit,* as it is called, which would otherwise draw a very heavy current and *burn out* the dynamo. The armature is the part that suffers first.

In talking about dynamos or generators (the two names are used for the same machine) we use the words

E. M. F. and *voltage.* By the E. M. F. of a dynamo is meant *the total pressure generated by the armature.* As the current flows through the armature and field circuits of a railway generator it encounters the *internal resistance* of the generator and pressure is lost according to the rule: Drop in pressure is equal to the product of the current and the resistance. Hence the current as it flows out of the generator is at a reduced pressure; and this pressure at which current is delivered to the switch board, is called the terminal voltage or simply the *Voltage* of the machine. For the generator like above Drop=C x R=2000 x 0.025=50 volts.

If we intend to deliver power at 600 volts it will be necessary to design the speed and the magnetic flux to produce a pressure of about 650 volts.

If a voltmeter be applied to the brushes of a generator just ready to go into service, but not yet carrying any load, the reading obtained is called the E. M. F. When the switches are closed and the generator furnishes power to the line the reading of the voltmeter will drop and its reading is called the *Voltage* of the machine.

We often speak of current being drawn from the dynamo. The generator keeps a steady pressure on the line of 600 volts and the flow of current is regulated by the load in the following way:

One locomotive hauling a train at speed will have a resistance of 0.3 ohm and will draw 600 divided by 0.3 or 2000 amperes.

It would be more accurate to say 2000 amperes are allowed to flow. This locomotive is the only path for current to pass from the feeder (third rail) to the return (rails). When two locomotives are in use there are two paths between the feeder and the return. The conducttivity between conductors has been doubled and the resistance halved. Double the previous current now flows.

In this way we get the current desired by lowering the resistance, and as the current passes it performs the work.

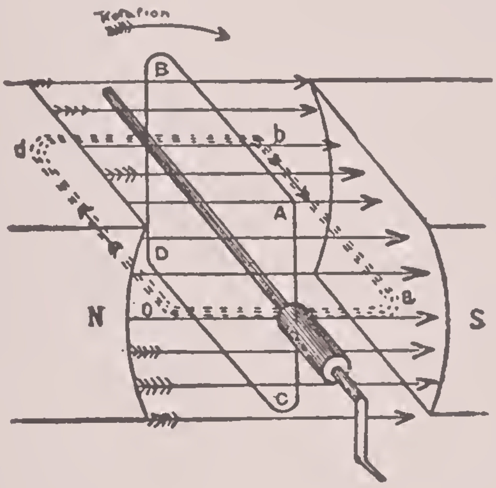

Fig. 179. Direction of Induced E. M. F. in Dynamo.

Two locomotives draw twice the current of one, hence their conductivity is double that of one, and their combined resistance is half of one.

The conductivity of three locomotives is treble, so their combined resistance or Joint Resistance is one-third that of one.

In the usual type of railroad generator, the revolving part is the armature and the stationary part the field magnets. Fig. 179 shows the elements of a dynamo, and as the loop is rotated there is an E. M. F. generated in it.

While the loop is coming into and passing away from the position ABCD, there is no E. M. F. generated, for the motion is parallel to the flux. As the loop moves towards the position ABCD by a uniform rotative speed it cuts the lines of force faster and faster, for first it cuts in an oblique manner but as the loop comes into the position of abcd the loop is moving straight across the flux. Hence the actual number of lines cut per second is least at ABCD and gradually increasing becomes greatest at abcd; thus producing an E. M. F. of varying value.

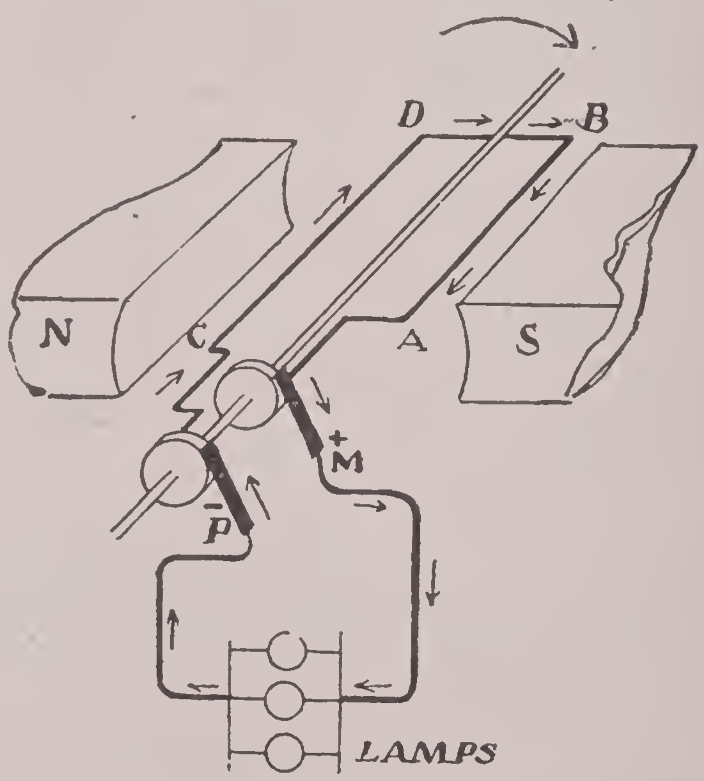

Fig. 180. The Simple Alternating Current Dynamo. Brush M Is Positive.

During this quarter of a revolution the wire BA has moved down in front of a S-pole inducing an E. M. F. tending to send current from B towards A. The other part of the loop CD has moved upward in front of an N-pole inducing an E. M. F. tending to send current from C towards D.

These results are in accordance with the experiments described at the beginning of the lesson. Remember that in applying the rule you must *face* the pole.

This action is repeated during the next quarter of a revolution, and when finally the coil is in the position ABCD with AB at the bottom the pressure is again at zero.

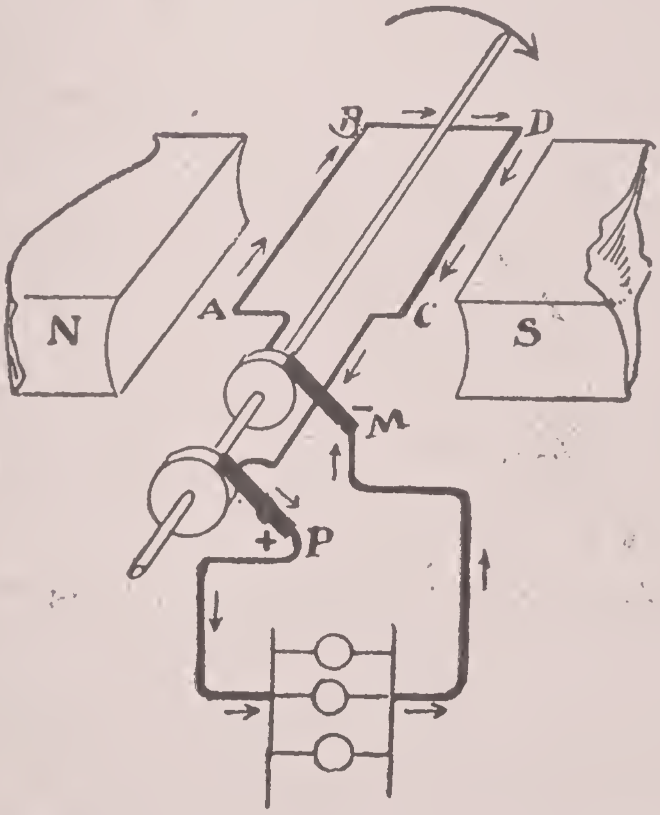

Fig. 181. The Simple Alternator, Shows Coil at One-half a Revolution from Fig. 180. Brush M is Now Negative.

The value of the E. M. F. has started at zero, risen to a maximum, and decreased to zero again. This gives a fluctuating current or pulsating current in the external circuit.

When AB rises in front of the N-pole the E. M. F. will be in the direction of from A to B, while before it was from B to A. During each revolution of the loop the current flows one way half the time and then is reversed and flows the other way.

This is what happens in the armatures of all dynamos whether alternating (A.C.) or direct (D.C.) current types.

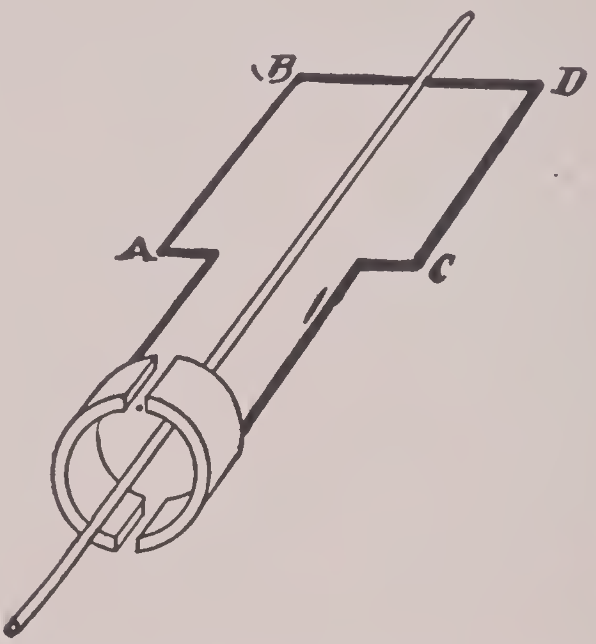

Fig. 182. An Armature Coil Connected to a Two-part Commutator, so as to Deliver Direct Current.

When we wish to utilize the current flowing in the loop of Fig. 179, we attach two collector rings as shown in Figs. 180 and 181, which gives us an A. C. generator or an *Alternator*. For a D. C. generator or simply *Generator,* the ends of the loop are connected to one ring split as shown in Fig. 182, whose halves are insulated from each other and from the shaft. Two brushes are placed as in Fig. 183. In this case the alternating E. M. F. will be *reversed* or *commuted* at the proper instant and there will be a one direction E. M. F. impressed on the external circuit. The split ring is called a *Commutator.*

THE ALTERNATOR.

In Figs. 180 and 181 are shown two positions of the loop on the armature of an alternator. The collector rings are insulated from the shaft and each other by mica. The terminals of the loop are soldered or riveted (sometimes both) to the rings and current is led to the external circuit containing the lamps by stationary strips of copper which form a sliding contact with the rings.

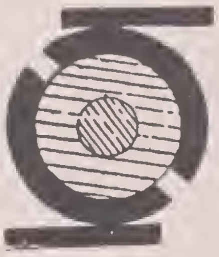

Fig. 183. Cross Section of Simple Commutator. Black Represents Copper; White Space Is Mica Insulation.

Look at Fig. 180 and notice that during the first half of the revolution of the loop ABCD, the direction of the E. M. F. in AB is from B to A, and in CD is from C to D.

The current flows from the brush M to the lamps so that M is positive.

Looking at Fig. 181 note that the wire in front of the S-pole is still positive, but that it is now the wire CD instead of AB, so P is the positive brush for the second half of the revolution. There are two reversals of the current per revolution.

The number of *alterations per minute* is the speed in revolutions per minute multiplied by the number of poles.

The number of *cycles* is found by multiplying the speed in revolutions per second by the number of pairs of poles. The number of cycles is usually spoken of as the *Frequency* of the alternator.

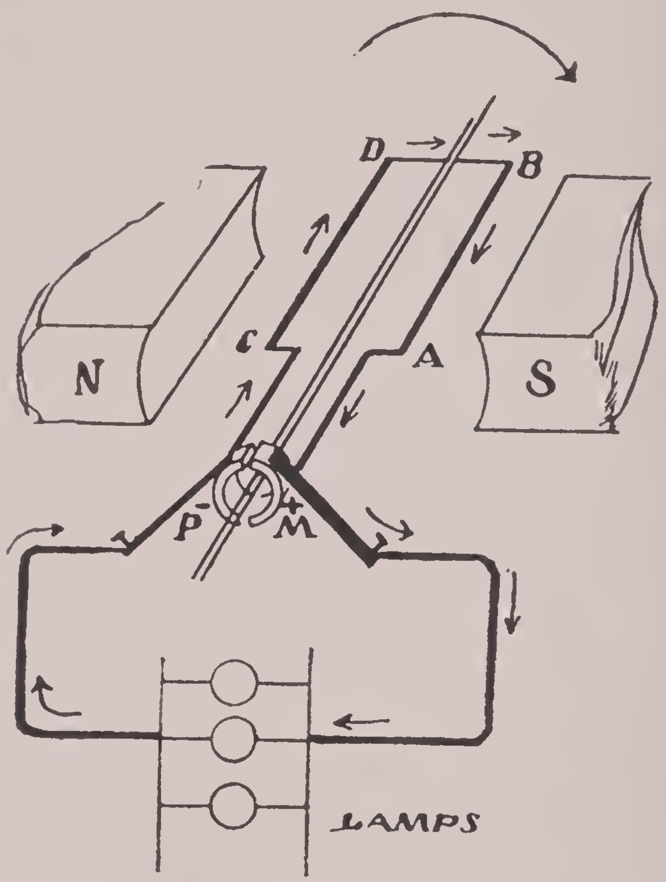

Fig. 184. Simple D. C. Generator. At This Instant the Brush M Is Positive.

The usual frequencies are for power 25, for motor circuits, and arc lamps 66, and for incandescent lighting 133.

THE DIRECT CURRENT GENERATOR.

In Fig. 184 is shown a loop and a two part commutator of a D.C. generator.

Since the wire AB is moving down past a S-pole, the current flows from B to A and out of the brush M, which is called the positive brush. In wire CD the current flows from C to D, making P the negative brush.

After half a revolution the wire CD is over where AB was, and is now delivering current towards the external circuit instead of away from it: *but CD is now connected through its commutator bar to brush M instead of to P so that the brush M is still positive.* (See Fig. 185.)

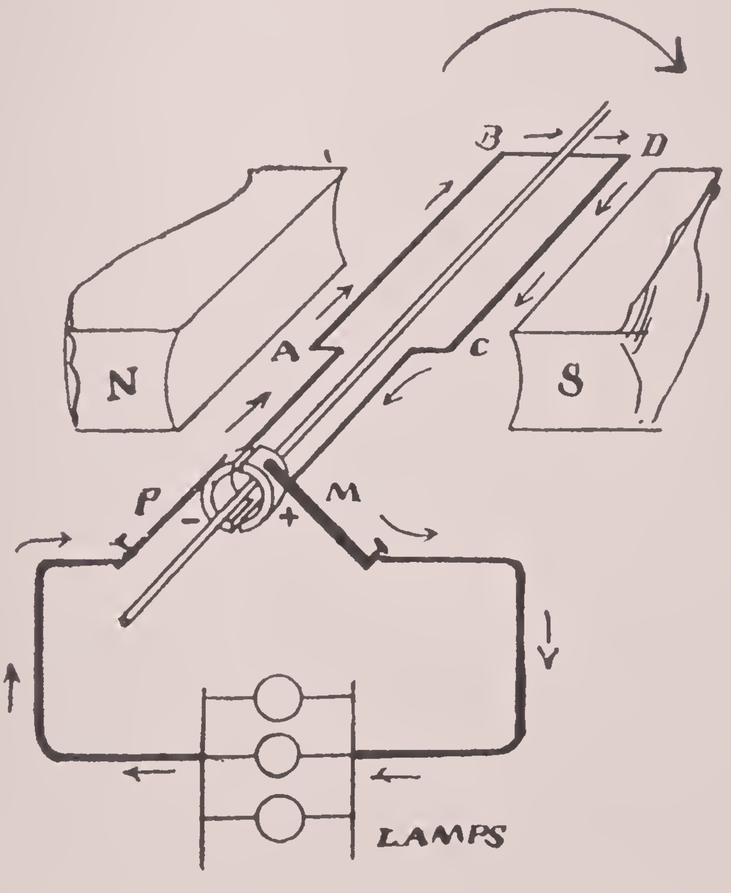

Fig. 185. Simple D. C. Generator. The Armature Has Made Half a Revolution, but Brush M Is Still Positive.

This arrangement of commutator bars and brushes performs the duty of connecting the brush M to that part of the winding, and only that part which is moving down in front of a S-pole. As long as the wire AB moves up in front of a N-pole the commutator connects it to brush P, but as soon as it begins to move down in front of a S-pole it is immediately disconnected from P and a connection made with M.

To increase the E.M.F. The greater the field strength the greater the E.F.M. and the higher the speed the greater the E.M.F.

When the speed has been raised until the surface of the armature is traveling at the rate of 3000 ft. a minute* no further increase is made, lest the bursting stresses become too great.

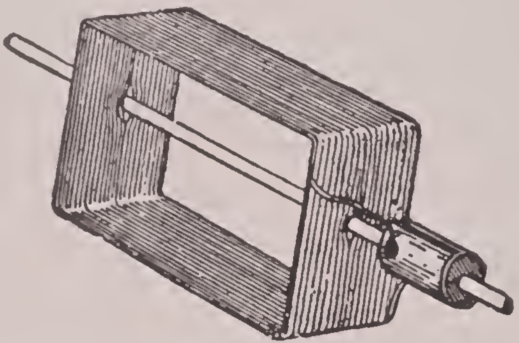

Fig. 186. A Single Coil Armature of Many Turns.

In order to further increase the E.M.F. more *turns* or *loops* of wire must be wound on the armature. A coil of 16 turns as in Fig. 186 will give an E.M.F. 16 times as great as a coil like Fig. 182. Looking at Fig. 187 will convince you of this.

Suppose the direction of rotation to be the same as the hands of a watch (or as we say, *clockwise*) when viewed from the commutator end of machine; then the

---

*This is called the Peripheral Speed of the armature and is calculated by this rule:

P. S. equals 3.1416 x D x R. P. M. where D is the diameter of armature in feet and R. P. M. is the revolutions of the armature per minute.

E. M. F.'s induced in the successive portions of the wire will be as shown by the arrows, and will add to each other, impressing a high E.M.F. on the brushes. We say that these turns of wire are all in *series.*

Any betterment of the magnetic conductivity of the frame of the machine will increase the E.M.F.; by producing a greater flux per pound of copper on the field magnets. Hence the winding of the armature inductors (wires) on a core of very softest iron is an economic necessity, resulting in either a higher E.M.F. or a reduction of the expense for copper in the field coils.

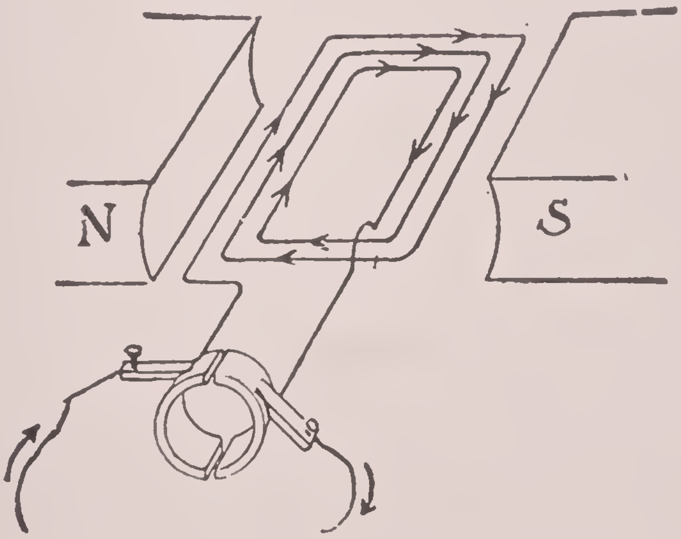

Fig. 187. An Armature Coil of Many Turns Showing How the Induced E. M. F. of Each Turn Adds Itself to That of Other Turns.

These cores are called *Drum cores* when the central hole is just large enough for the shaft and the insulation around it (Fig. 188); and are named *Ring cores* when the internal diameter of the ring is much larger than the shaft. (Fig. 190.) The armature in Fig. 191 has a ring core, but the end plates being in position, the large hole is concealed.

These cores are built up of a great many punchings of soft iron from 15 to 40 mils thick, pickled so as to rust them a little. Every tenth one is varnished or tissue paper pasted on. The rust, varnish and paper are all insulators and when the punchings are assembled in a core prevent currents called *Eddy currents* from flowing from one end of the armature to the other and heating it.

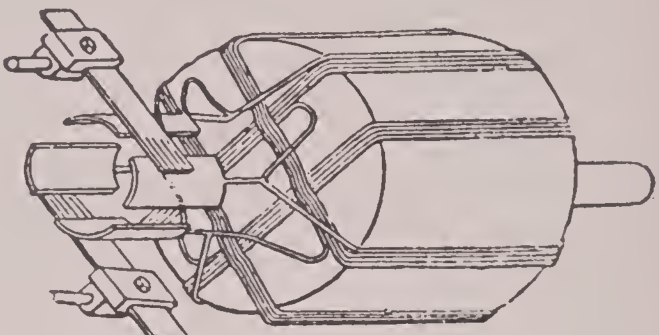

Fig. 188. Drum Winding on a Drum Core. Four Coils, and Four Commutator Bars. For Direct Current.

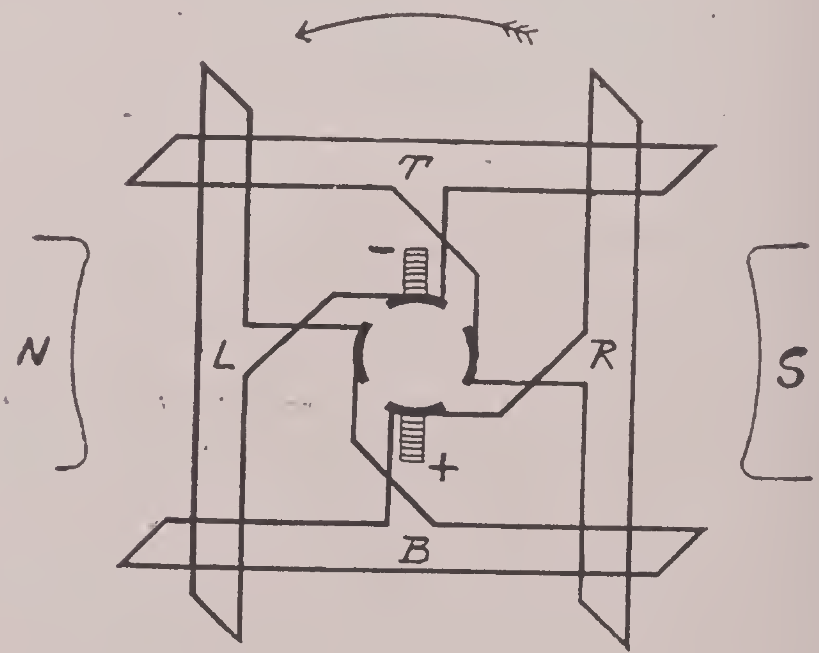

Fig. 189. Diagram of Fig. 188.

These cores are sometimes *smooth* but more frequently are *slotted* with the wires laid in the slots.

About 10 to 15% of the length of the core is insulation, and about 50% of the surface is slots containing the inductors.

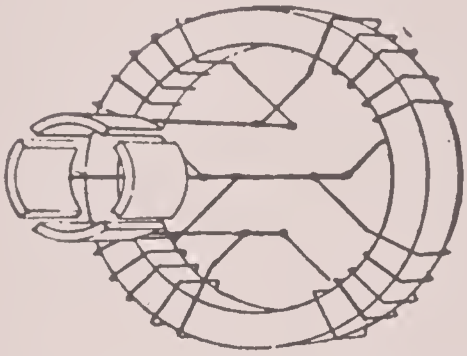

Fig. 190. Simple Gramme Ring Winding.

To get a Continuous E.M.F. While a single coil of many turns produces a high E.M.F., which by a two part commutator is always applied to the external circuit in the same direction, yet this coil passes through all the changes in voltage mentioned in connection with Fig. 179.

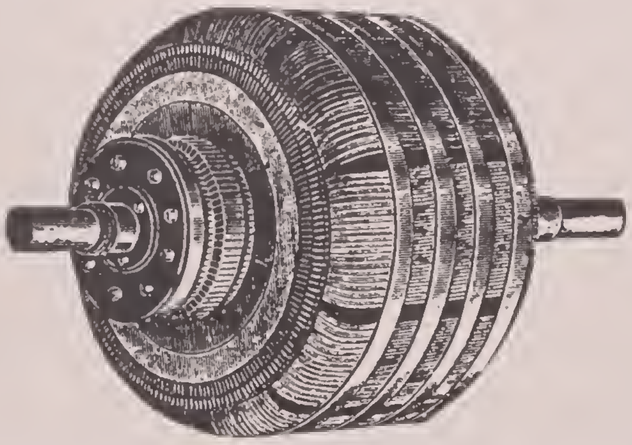

Fig. 191. Eight Section Eighty Coil Ring Winding on a Smooth Ring Core, with Eighty Bar Commutator. For Direct Current.

Examine the ring winding (invented by Gramme) of Fig. 190, which is wound on a ring core made up of soft iron punchings 25 mils thick.

The wires on the outer surface are *active,* having E.M.F. induced in them, and are called *armature inductors.* The rest of the wire is *dead* wire and only useful to complete the circuits between inductors.

Notice the connections between commutator bars and winding. Number the coils and commutator bars with a pencil, sketch in the two magnetic poles and the two brushes. Imagine the armature to rotate clockwise and figure out the value of the voltage at the brushes during different parts of a revolution.

In Fig. 192 we have the same windings with eight coils and eight commutator bars. In Fig. 191 the armature as diagrammed in Fig. 192 is shown completed with its four bands. These bands are from 12 to 25 convolutions of phosphor-bronze wire in sizes varying from No. 20 up to 14 laid on tightly over a mica insulation and sweated with solder all the way round.

In Fig. 192 you will notice that the complete winding can be divided into two parts, one influenced by the N-pole, the other by the S-pole standing at the commutator end. The N-pole side moving upwards has its E.M.F. in direction from back to front of armature *through the inductors;* the S-pole side has E.M.F. in direction from back to front of armature *through the dead wire.*

In winding the armature the wire is laid on in a continuous spiral as shown. This makes the E.M.F. in each half of the armature in series, and allows the current to flow from one coil to another, except at the points where the N-half and S-half of the armature meet. Here the E.M.F.'s oppose and if wires were connected for an instant to the winding, as shown in the picture, the two opposing E.M.F.'s would both force electricity out into the wire at the top of the armature and draw it in at the bottom as shown by the arrows on these wires. This will cause a current to flow in the external circuit.

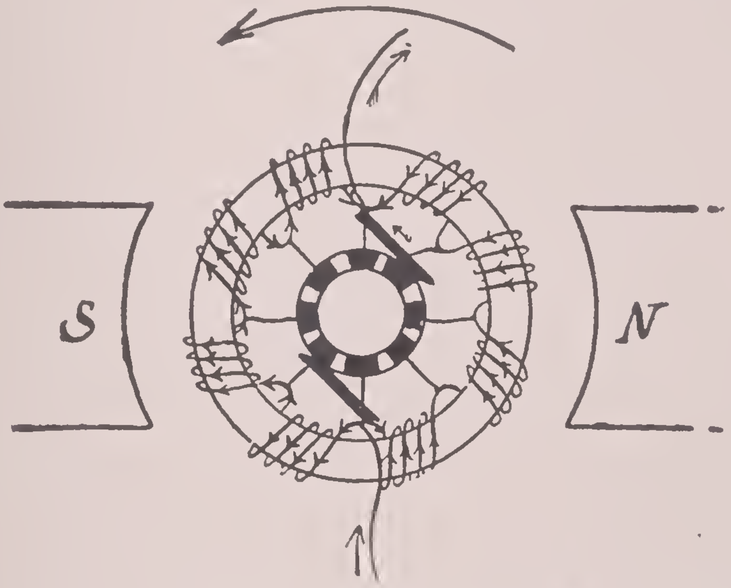

Fig. 192. Eight Coil Gramme Ring Winding, with Eight Part Commutator.

If the junctions of the coils are connected to eight commutator bars (one bar per coil) and connect the ends of the external circuit by brushes to the commutator bars which are midway between the N- and S-poles, then each half of the armature separately generates an E.M.F. and delivers current to the external circuit.

Suppose the armature to be revolving at the highest safe speed. Each inductor will move past the magnet poles at a speed of 3000 ft. a minute. With pole pieces 5 x 8 inches and a *flux density* of 90,000 lines per square inch, the *total flux* will be 5 x 8 x 90,000 or 3.6 million lines.

The armature may be 9 inches in diameter, which gives its rotative speed 1270 (nearly).

For R.P.M.*=P.S.†÷(3.1416 × diameter).

$$= \frac{3000 \times 12}{3.1416 \times 9}$$

$$= 1270 \text{ nearly.}$$

which R.P.S.‡=21 nearly.

An inductor therefore cuts 3.6 million lines of magnetism twenty-one times a second, which is equivalent to cutting 75.6 millions once per second.

Since the cutting of 100 million lines per second by an inductor induces 1 volt pressure, each inductor on this armature revolving in this field will produce 75.6÷100 or ¾ of a volt (aprox.).

The 4 coils of 4 inductors each (Fig. 192) on the N-half of armature being in series produces 3 volts per coil or a total of 12 volts *which is the E.M.F. of the generator.*

The S-half of the armature also generates a pressure of 12 volts, which is not added to the pressure of the N-half, being in parallel with it. An inspection of Fig. 192 shows that they oppose rather than add to each other; but an outlet being provided they turn aside through it, and send current separately and independently towards the outside circuit.

If the armature is wound with No. 10 A. W. G.,§ the diameter of which is 0.102 inch or 102 mils, its area is 102 squared equal to 10,404 c.m. Allowing 700 c.m. per ampere, it will carry 15 amperes, without too much heating.

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*Revolutions per minute.

†Peripheral speed.

‡Revolutions per second.

§American Wire Gauge. A table of sizes and properties of the sizes of wire according to the Brown & Sharp or American Gauge will be found in Lesson 18.

Since each side of the armature delivers its own current to the brushes, the safe current output of this generator is 30 amperes.

Suppose there are 250 ft. of this No. 10 wire on this armature. The resistance of the wire from the wire table is 1.02 ohms per 1000 ft.

The resistance of *all the wire* on armature is 0.255 ohm, and the resistance of the wire on each *half* of the armature is 0.128 ohm.

But the two halves are in parallel so *the resistance of the armature as measured from brush to brush* will be half of 0.128 or 0.064 ohms.

The drop or loss of pressure in armature will be C×R or 30×0.064, equal to 1.92 or say 2 volts.

This machine being a *shunt generator,* the main current does *not* pass through the fields, and there is no further voltage loss.

The E.M.F. of this dynamo is 12 volts and its *voltage* 10 volts. Its output in watts will be 10×30=300 watts or 0.3 kw. This is the *rating* of the generator.

The generator will carry this load 22 hours a day without getting more than 90° Fah. hotter than the surrounding air.

A properly proportioned machine will stand a 25% overload for half an hour rising an extra 30° in temperature, and it will stand a 50% overload for one minute without being damaged by the heat.

Drum Windings.

The extra labor involved in passing the dead wire through the bore of a ring core is avoided by going back to first principles again and placing on the core (either drum or ring) a number of coils shaped as in Fig. 186, producing a winding as in Fig. 188.

It is to be noted that the inductors lie entirely on the outer surface of the core and that the percentage of dead wire is less than in Fig. 190.

For a long, small diameter armature drum winding uses the least wire; while for a short, large diameter core the ring winding will require fewer pounds of copper.

Take Fig. 188 and mark in pencil as directed, using Fig. 189 as a guide. In order to make the diagram in Fig. 189 clear, it has its proportions wrong. The dead part of the wire is drawn very long and the active part very short. The reverse is true of an actual winding.

Mark the top horizontal coil of Fig. 188 T, the bottom one B. Mark the right and left hand vertical coils L and R. Mark the upper brush negative and the lower one positive.

The left side of the armature is the N-pole side and the right the S-pole side; then we know that the armature is revolving anti-clockwise (else the upper brush would be positive).

The E.M.F.'s on the N-side and S-side of coil T, just as in Fig. 187, are in series and add producing a current flow towards the lower (positive) brush. The current passes through the inactive (dead) coil R in order to get to positive brush.

At the same time the E.M.F.'s in coil B add up and passing through the dead coil L drive current out of lower brush.

The value of the E.M.F. is eight times that which one inductor can produce. For the active coil T has 4 loops, i. e., 8 inductors in series, as also has the coil B. Suppose T produces 8 volts, the two coils T and B are in parallel and do not add their E.M.F.'s.

The coils L and R are dead, L being in series with B and R in series with T, but they produce no E.M.F. At the present instant they are but a wasteful resistance, their value, however, will be soon seen.

When the armature has moved about ⅛ of a revolution, you will find that T is cutting flux slantingly and that R, which is in series with it, is beginnng to cut flux also. T is only ¾ active, producing say 6 volts, and R is not totally dead but ¼ active, producing 2 volts. Hence the voltage of the machine is still 8.

At ¼ revolution R is doing full work and B is dead and in series with it, while T is dead and L in series with it is at full activity. Now R and L produce the E.M.F.

The student must revolve Fig. 189, using slips of paper as brushes to gain a full understanding of these actions.

The current enters the armature through the upper brush, splits and passes through the armature by two parallel circuits, one containing T and R in series and the other containing L and B. During a revolution these coils interchange places, but two coils are always in each circuit.

When 6 amperes flow in the external circuit, the No. 16 wire of the armature is not overheated, as it only has to carry 3 amperes (half of 6), which it is well able to do. It has 2583 C.M., and which is more than 3×700 C.M.

Self exciting of a Dynamo. When a dynamo is standing idle the field magnets are weakly magnetic due to residual magnetism.

Let the armature revolve and in a shunt or compound machine open, in a series generator close the external circuit.

A few volts will be generated and cause a current to flow through the fields, hence the magnetism will increase and more voltage will be induced. This voltage will send increased current through the shunt field and cause more volts to be induced.

The machine is now *"building up."*

As more and more magnetism is put into the fields, it becomes harder to get any more in as the iron is approaching *saturation* and there is more and more *leakage.*

Hence at a certain point, depending on the design of the machine, the difficulty of increasing the magnetism being added to the effect of the leakage just balances the tendency of the voltage to be increased. If nothing else is done the voltage of the dynamo will remain constant.

In the series field is passing all the current drawn from the machine and the field strength and voltage tend to increase. This increase is opposed by the C. R. loss in armature and field, and the effect of the increasing field density. The net result is a *building up* of the voltage and if the load is not changed the voltage of the machine will remain constant.

Regulation. If now in the shunt generator you close the external circuit an extra current (very large in proportion to the field current) is drawn from the armature and causes a C R loss.

A lower voltage is thus impressed on the external circuit and to make matters worse, also on the field. Hence the field weakens and the added results of C R loss and weaker field is a considerable drop in voltage for each increase in load.

Resistance must be cut out of field as load increases.

When in the series generator the load increases a shunt should be placed around the field to weaken it, if a constant potential is desired.

Position of the Brushes. In order that one set of brushes may take away from and the other set deliver current to the generator in a bipolar machine these sets are on opposite sides of the commutator.

In some dynamos when the inductors come out of the slots, one goes straight on to a commutator bar and the other is bent over to its proper bar. This puts the brushes in line with part of the coil and they will be found half way between the pole tips.

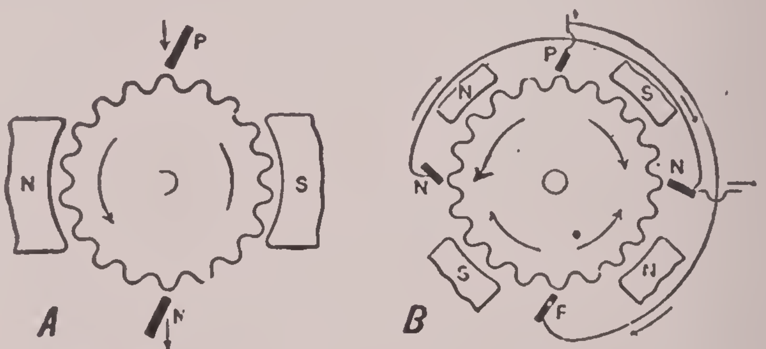
It is usual to bend both inductors as they leave the slots and connect to bars half way between the slots. Then the brushes will be found opposite the middle of the pole piece.

In dynamos and non-reversing motors the brushes are a little distance away from the points mentioned, but in reversing motors are exactly at these points.

If you will consider that a multipolar dynamo or motor is merely a lot of bipolar fields which for economy of material are working on one large armature, the placing of the brushes on such machines will be clear to you.

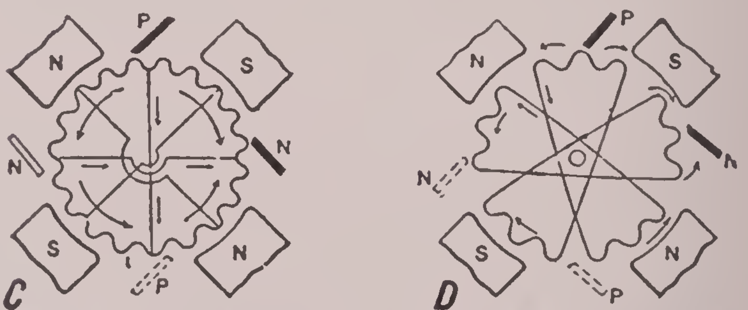
The alternate brushes are of the same polarity and there is usually a set of brushes for each field magnet.

The placing of the brushes on the commutator with a certain relation to the winding is necessary as a reference to Fig. 193 or to the diagram of any winding will show you that the brush while collecting current is at the same time *short circuiting* one of the coils.



Two Pole, Two Circuit

Four Pole, Four Circuit, Four Brushes in Multiple.



Four Pole, Four Circuit, Cross Connected Two Brushes or Four Brushes, in Multiple.

Four Pole, Two Circuit Ring Two Brushes or Four Brushes, in Multiple.

Fig. 193. Showing the Number and Position of Brushes on Different Armature. Windings.

The black brushes are the ones actually used, the dotted ones being dispensed with on account of the particular winding.

In order that an excessive current may not be generated in this short circuited coil it must be out in the interpolar space at the time the brush touches the two bars belonging to it.

Sparking. When a current is broken there is always a spark, which is greater the more turns in the wire and the more iron within these turns. That is, the more *inductive* the current the worse the spark.

The conditions are right for excessive sparking in a machine, for the circuit is *inductive* and although the circuit is not actually broken, the current being merely shifted, yet the result is equivalent to it.

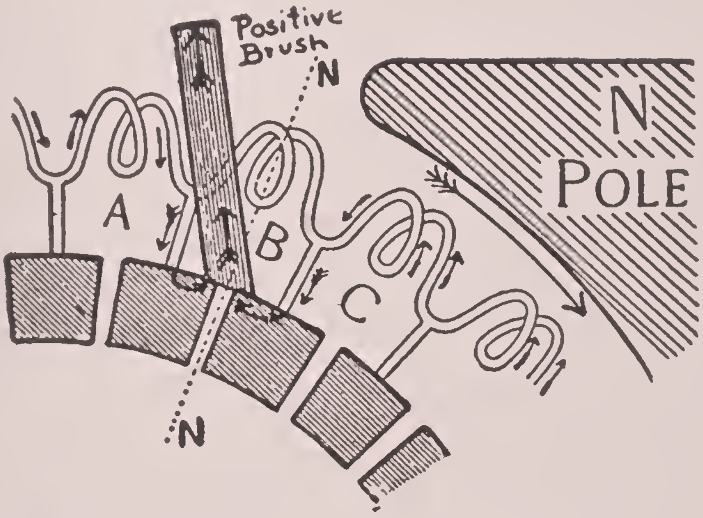


Fig. 194. Showing Position of Brush for Sparklers. Collection of Current.

Looking at Fig. 194 and considering the line N N to be about midway between the pole pieces. The coil B is short circuited but has no current in it because

1st. The field is very weak and the coil is moving parallel to it, so no E.M.F. is generated in the coil.

2d. The currents from the N and S-side of winding enter the brush without going through the coil B.

Coil B has therefore no *current* in it, but being connected to A and C whose potential is high B is *charged* with electricity, and it is full of *coulombs,** which are at rest.

When the armature revolves as shown and the toe of a copper brush leaves bar 3 the current from C must instantly change over going through B to reach the brush. The coulombs in B which are at rest should instantly move at full speed becoming a part of the armature current.

It being impossible to set the coulombs in B into motion instantaneously it is evident that the current from C encounters *more* than the *ohmic resistance* of the coil B. This extra opposition being called *reactance.*

The path through B being momentarily practically nonconducting the circuit is broken by the brush moving away from the bar, and a spark or arc formed.

The circuit being *inductive* (having turns containing iron) the spark is persistent and holds until the *reactance* of coil B decreasing, it begins to conduct and diverts enough current into the proper path and the arc goes out for lack of current to maintain it.

This *sparking* is avoided in the following way:

1st. Carbon brushes of high resistance are used which, as the part of the brush touching a bar gets narrower, due to the high resistance, throttles the current, gradually forcing it over to the coil B. Hence B does not have to instantly carry *all* the current.

2d. Move the brushes of a dynamo in direction of rotation until they are nearer the pole shoe, exactly as is shown in Fig. 194.

---

*A coulomb is a certain quantity of electricity. When a coulomb passes a given point every second a current of one ampere is said to flow.

The short circuited coil B is now under the *fringe* from the pole piece; and is moving obliquely through a stronger field. A small E.M.F. is generated in it.

From the illustration it will be seen that a current in the same, as in C (for B and C are under influence of same pole piece) flows around through B, the bars 2 and 3 and the brush.

By *shifting* the brushes a little to and fro the correct strength of field can be selected and the obliquity at which it is cut adjusted, so that a current will be made to flow in B not only of *the same direction as that in C* but also of exactly the *same value.*

Hence when the toe of the brush slips from bar 3 the current in C instead of running against the *impedance* (the sum of the resistance and reactance) of coil B, finds itself merely falling in behind the flow already established, and there is no tendency to spark.

In a motor the brushes are shifted in opposite direction to the rotation to get to the no sparking position. Hence the positions for sparkless forward or backward running are some distance apart.

It is a mere matter of first cost to produce a machine with absolutely *sparkless commutation* under any conditions. It is the skill of the designers which has (without prohibitive cost) so reduced the distance between these two points that it may be spanned by a thick carbon brush.

The railroad motor of to-day operates in either direction, without shift of brushes, under all loads, and some overloads, without serious sparking. What little occurs is of such small volume and such low temperature that no great harm is done.

Classes of Dynamos.

Dynamos are divided into classes with reference to the manner in which their fields and armature are inter-connected.

The series dynamo. Fig. 195. The same current traverses the field, armature and main or external circuits. The conductors in these circuits are about the same size. The circuits are all in *series.*

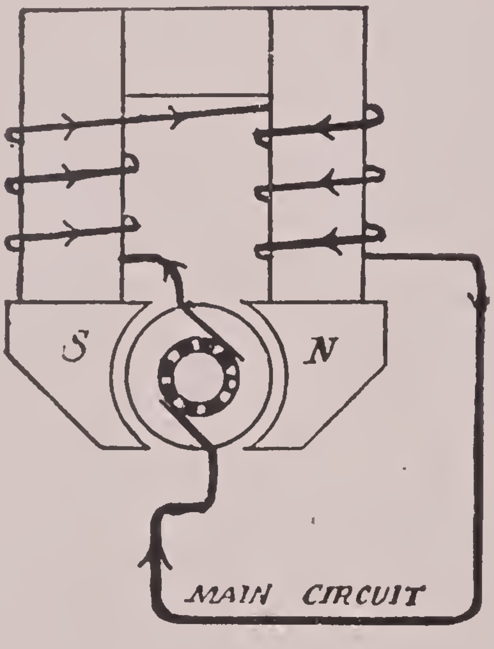


Fig. 195. Circuits in a Series Dynamo or Motor.

This dynamo is used for arc lighting and as boosters for increasing the pressure on a *feeder* carrying current furnished by some other generator.

The characteristic of this type is to furnish power at an increased voltage as the load increases. If sufficient current is drawn to overload the machine the voltage will fall.

The shunt dynamo. Fig. 196. Here the field circuit is arranged as a shunt circuit. The armature and external circuits are in series. The armature current is the sum of the external and field currents. The conductors on the field are very much smaller than those on armature, as they only carry 2 to 5 per cent as much current.

Used for incandescent lamp lighting, mill and factory power.

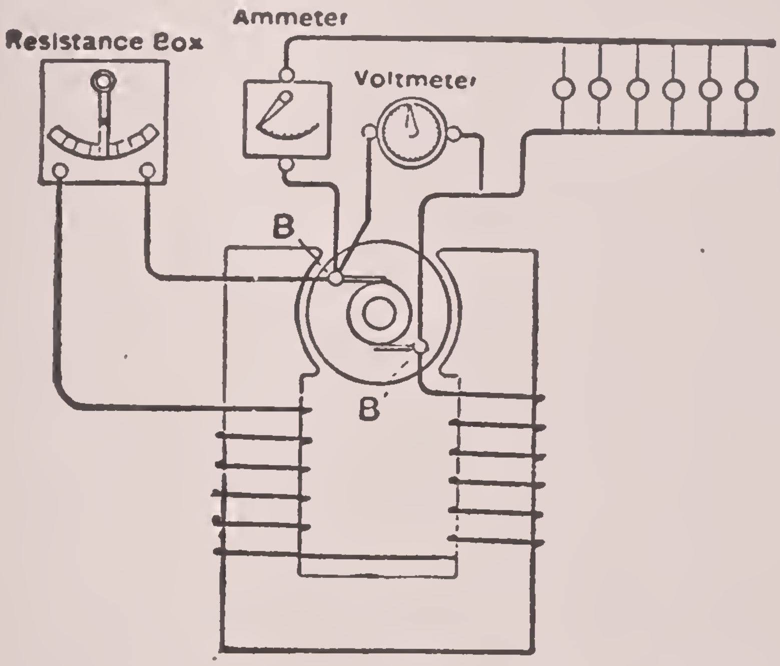


Fig. 196. Circuits of a Shunt Dynamo with Instruments and a Load of Lamps.

The characteristic of the shunt generator is to allow the voltage to fall as the load is increased.

It is evident that only by a combination of these two into a *compound dynamo*, Fig. 197, can a generator be produced which will deliver any power within its rated capacity and yet hold a steady voltage.

The armature is the same as a shunt dynamo, but the fields have two distinct windings, one shunt and the other series.

The series dynamo is often called a *constant current* generator because its tendency is that way, and with a regulator it will furnish a constant current.

The shunt dynamo is similarly termed a *constant potential* generator. For with a regulator it will keep to a constant voltage.

The compound generator will of its own accord, without any regulator, furnish at its terminals or at any distant point on the line steady power, at an absolutely constant voltage.

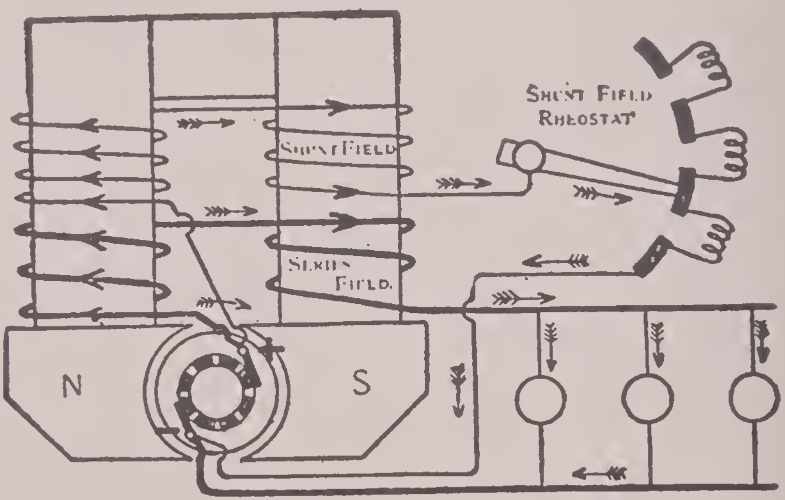


Fig. 197. Circuits in a Compound Dynamo.

In railway service where the amount of power required fluctuates violently, the voltage will vary somewhat, for the generator scarcely has time to adjust itself to the present conditions before the condition no longer exists and a new demand arises.

It is not necessary that the pressure on the third-rail should be absolutely constant, and for this kind of service the compound generator, with the series characteristic predominating, so as to keep a steady pressure *out on the line* is good and plenty.

LESSON 25.

MOTORS.

It might be said that another class of dynamos is *motors.*

Any of the D. C. dynamos and many of the A. C. machines in power houses would revolve and produce mechanical power if they were supplied with the proper kind of current at proper voltage. In fact, one of the troubles that may occur in a power house is to have one out of a set of generators start to act as a motor, thus placing heavier load on all the other machines.

The same electrical machines can be used as a dynamo or a motor; but as most dynamos are *compound* or *shunt* and built for power houses, where there is sufficient, if not plenty of room, and as all railroad motors are *series wound* and placed where there is very little room, it is natural that the dynamos and motors a railroad man sees should not look alike.

The similarity of their electrical action must be remembered so that one may understand that the parts of a dynamo and motor, though a little different in shape, act alike electrically and have the same names.

Comparison between Dynamo and Motor. Since it takes power to force a dynamo armature to revolve while generating current, and none when not generating (field and armature circuits open) we conclude that it is the action between field and armature magnetisms which causes the dynamo to resist rotation.

To test truth of this remove the armature from the fields and pass current through its conductors *in same direction as the flow was before.* You will find that the armature is a large, strong electro-magnet.

Testing the polarity of the field magnets and of the armature poles you will find that where using as a dynamo, we are forcing a N-armature pole towards a N-field pole. These poles repel each other and power is absorbed by the rotation of the dynamo.

The repulsion of these poles would make the armature rotate if current were supplied to it and the fields, and the steam engine removed.

The difference between ordinary and railway motors is the extreme simplicity of the latter.

Many of the refinements of design and construction which theoretically are necessary, are in railway motors omitted. It being found that for successful operation they are *not* necessary, and by their omission much is gained, i. e., saving in weight, cost, number of parts, absence of complication and ease of repair.

It is not needful to say that parts of a railway motor are put together so as to "stay put."

That motor is best, which with the fewest pounds of material, will with reliability and low cost of repairs propel the greatest number of tons of pay load.

The main differences between all motors and dynamos are the method of starting and the effect of the E.M.F. produced.

Starting Motors.

We can not turn on steam to an engine instantaneously, for it takes time to open the throttle. We do, however, turn it on more slowly than the opening of the throttle compels us, for we wish to give the engine and its dynamo time to get up to speed.

In the same way we must give current to a motor easily, in order to start it. On the closing of a switch the current jumps up to full value so quickly that the motor armature would be brought up to such a temperature as would char the cotton insulation on the winding.

In starting a motor an extra resistance is used, and it is placed either in the main or armature circuit. It is only in use for a few seconds at a time and if well ventilated can be made very small and light in proportion to the current passing.

When applied to small motors where the starting is at infrequent intervals this starting rheostat and its operating drum and handle is combined with two automatic protective devices and contained partly in a latticed iron box and partly on its cover. It is called a *starting box.*

For larger motors doing similar work and for traction or railway work, each of the parts becomes so large that the four pieces are mounted separately. The operating drum, the resistances, the overload release and the no voltage release.

The operating drum is familiar to us all as the *controller* of the street cars.

The *resistance* in the form of cast iron girds held in skeleton frames are fastened under the sills of the cars.

The *overload release* or *circuit breaker* automatically opens the circuit when a current large enough to damage the motors is accidentally drawn. In street cars this device is usually fastened under the hood over the motorman's head.

No voltage release, a magnetically operated switch or series of switches kept closed by the magnet, thus giving the current access to the motors circuits or the circuits controlling them.

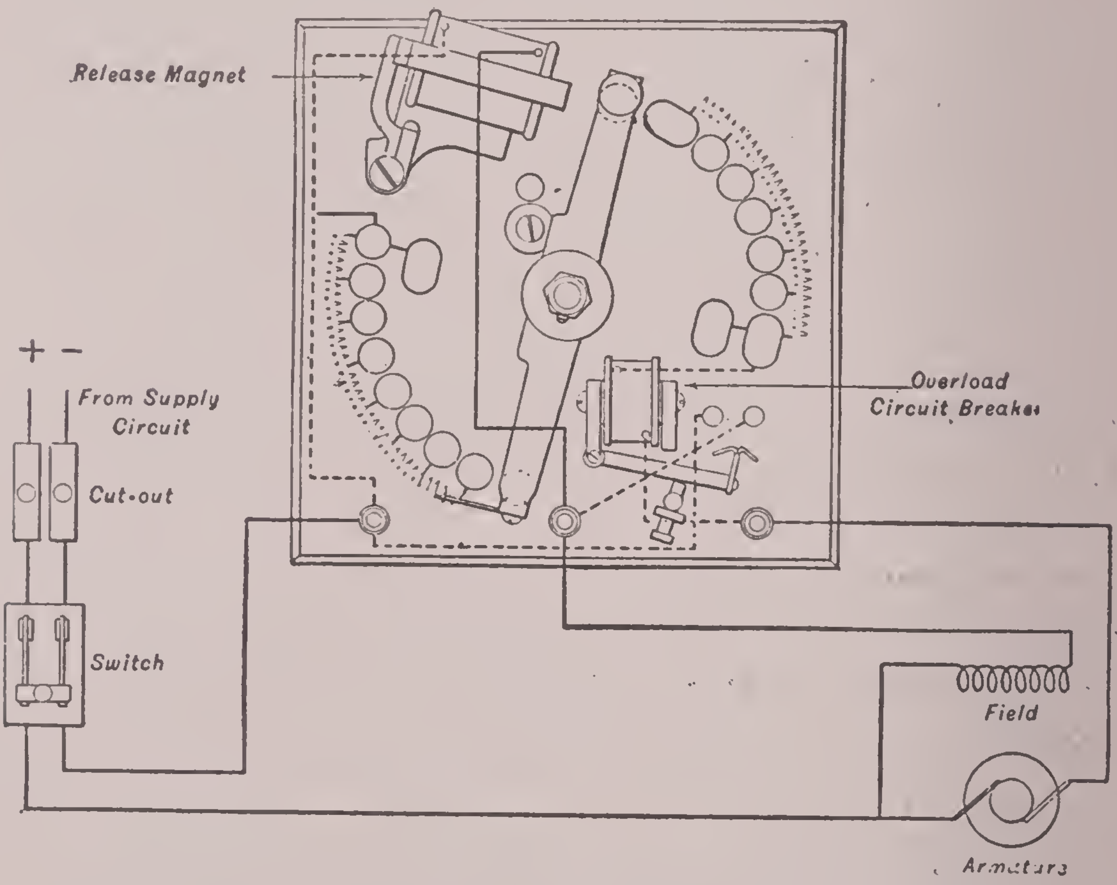


Fig. 198. Starting Box and Connections for Shunt Motor.

If the power is cut off the line the device operates, opening all the circuits leading to the motors, thus protecting the motors from the damage done by applying full voltage suddenly to a motor while standing still.

Fig. 198 shows a starting box with the proper connections ready to start a *shunt motor*. (Off position.)

As soon as the switch is closed there is full voltage on the field, but no voltage on the armature, as the circuit is open at each end of the starting arm.

As the arm is swung clockwise, current flows to armature through a resistance which gradually grows less, until when at right angles to its original position the full voltage is on the armature and the motor operating at full speed.

The hook on the left end of the arm catches on the knuckle at the lower left side of the release magnet and holds the arm in spite of the effort of a coiled spring (not shown) to return arm to *off* position.

Tracing the circuits will show that the release magnet is always energized if the supply circuit is *alive* and switch closed. Should the supply be interrupted the release magnet becomes demagnetized and the upper end of the knuckle is no longer held. The knuckle turns on the pin (with screw head) releasing the hook, and the spring returns the arm to the *off* position.

The motor would have stopped itself, but now it can only be restarted in the proper way.

Consider the arm in the "running position," the *overload circuit breaker* magnet in energized, but the armature* being a considerable distance away the magnet is too weak to draw it up.

Should the motor be overloaded and too much current pass the strength of this magnet is increased so that the armature swings up and jams the jumper in between the two studs shown on the right of the magnet. This completes a *shunt* or by-pass circuit around the release magnet, diverting enough current from it that it weakens and releases the knuckle. The arm then flies back to the *off* position and the circuit to the armature is opened.

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*Armature or keeper of a magnet; not of a dynamo.

The motor is stopped, which may be inconvenient, but it is to be preferred to a *burnt out* armature.

In a railway motor this heavy current would also pass through the fields, but they are better adapted to stand heat and the armature usually suffers first.

To start a motor with this *box,* close the switch and swing the starting arm from *off* to *running* position and let go. The overload circuit breaker may have danced up and down while this is being done. If so, next time swing arm more slowly.

To stop the motor *open the switch.* The motor will slow down and stop. Just before stopping, the release magnet will allow the starting arm to return to the *off* position.

The cutout shown consists of a fuse enclosed in a cardboard tube and designed to melt or *blow* at a current a little higher than that for which the circuit breaker is adjusted.

COUNTER E. M. F.

Counter E. M. F. When the motor is operating all the parts and conditions of a dynamo are present, hence there is a dynamo action which produces an E. M. F. in opposite direction to the *impressed E. M. F.* supplied by the line.*

This is a most important and useful action.

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*This I know by using the rule: Place the thumb, first and second fingers of the right hand all at right angles to each other.

1st Thumb in direction of the motion.

2d First finger pointing from a N-pole to a S-pole.

3d Second finger shows direction of induced. E. M. F.

You will see that when we are starting a motor that the faster it moves the more C. E. M. F. it generates. This is why we can not throw full voltage on a motor until it is nearly up to its full speed.

The actual voltage sending current through a motor is the difference between the impressed and counter E. M. F.'s.

The working of this in actual practice is best shown as follows:

Suppose a set of four motors are on a 600-volt line making 460 revolutions per minute with 44-inch wheels. The locomotive they are a part of weighs 100 tons and pulls 350 tons behind it at 60 miles per hour.

It is on a level track and must exert a pull of 17½ pounds for each ton pulled or 6,125 pounds in all.

It must exert through its drivers at the rail head 6,125 pounds for the train behind and 1,750 pounds for its own weight. The total tractive effort is therefore 7,900 pounds (7,875 to be exact).*

At 60 miles per hour a train moves 5,280 feet per minute; so the motors move 7,900 pounds 5,280 feet a minute which is 41,700,000 foot pounds per minute. Since 33,000 foot pounds per minute is a *Horse Power,* we get the H. P. of the motors as 1,264.

The efficiency of the locomotive is 80%, *i. e.,* the motors waste 20% of the intake. Hence 1,580 H. P. is taken from the line.

This is expressed in *Kilo Watts* by multiplying by 746 and dividing by 1,000 giving us 1,185 K. W.†

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*With certain problems a foolish amount of accuracy in figuring is a waste of time. Since the condition of the rails is a variable quality in traction work, figuring on the *safe side* is the only sensible way to work.

†There are 746 watts in 1 H. P., and 1000 watts in a K. W.

This being supplied at 600 volts needs 2,000 amperes (1,975).

An ammeter placed in the main conductor of one of the New York Central locomotives will read about 2,000 amperes when pulling train No. 51 or No. 41 along the Hudson River towards Croton, N. Y.

What is it that limits the current in this case to 2,000 amperes, *i. e.*, to 500 amperes per motor? Certainly not the ohmic resistance of them.‡

The resistance of *each* motor is only 0.1 ohm or all four in parallel or multiple is 0.025. The current is limited by the dynamo action of the motors, *i. e.*, by the counter E. M. F.

Each of the motors generates about 1.2 volts per revolution per minute, hence at 460 revolutions per minute the C.E.M.F. of each motor is 550 volts. This neutralizes all but 50 of the 600 volts on the line, and leaves that 50 to send current through the resistance of the motor. Fifty volts on 0.1 ohm gives 500 amperes or 2,000 amperes for all four motors.

Now let the train strike a grade. It will slow down in speed and drawing more current develop in its motors the H. P. required to pull the train.

How can motors whose resistance is fixed draw more current when the line voltage is constant? By means of the C.E.M.F.

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‡By ohmic resistance I mean the actual resistance of the material the conductors are made of. There is another resistance which depends on the rate at which a current *changes*, and has nothing to do with the material. Counter E. M. F. acts like resistance, as it opposes the flow of current. The *apparent resistance* of a locomotive drawing 2000 amperes is 0.3 ohm for 600÷0.3=2000. The actual ohmic resistance is 0.025 ohms.

If the speed drops to 55 M.P.H. then the R.P.M. of the drivers (and armature) change to 422, and the C.E.M.F. to 510 volts. Hence 90 volts acting on each 0.1 ohm motor passes 900 amperes, or 3,600 for the whole locomotive.

LESSON 26.

PARTS OF DYNAMOS AND MOTORS.

The following is a short description of the various parts of a *dynamo* or *motor* and an explanation of the terms used in talking about them.

Base. Made of cast iron and supports the magnet yoke and bearings. It is made hollow to save unnecessary weight, and is braced internally with ribs to give strength. It is bolted to a masonry foundation.

Railway motors have no base; the yoke being bolted to the transoms of the truck, either directly or through a spring supported lug.

Yoke. The ring or shell steel casting to which the magnet cores are bolted. Sometimes the cores are placed in the mold and the yoke cast around them.

In *railway motors* the cores are so short that they are frequently cast solid with the shell.

Pole pieces or faces. Generally of cast iron bolted or keyed to the magnet cores. Being greater in area than cores they serve to hold the field coils in place.

In *locomotives* they are sometimes made of sheet iron.

Magnet cores. Very seldom made of sheet iron, sometimes of wrought iron forgings, but generally are steel castings.

Fig. 199 shows a field coil and a magnet core of an alternator. The winding of copper ribbon wound edgewise. The pole piece is almost same size as coil.

Fig. 200 shows a shunt and series coil (large one is shunt coil) wound and taped ready to be shipped on the magnet core.

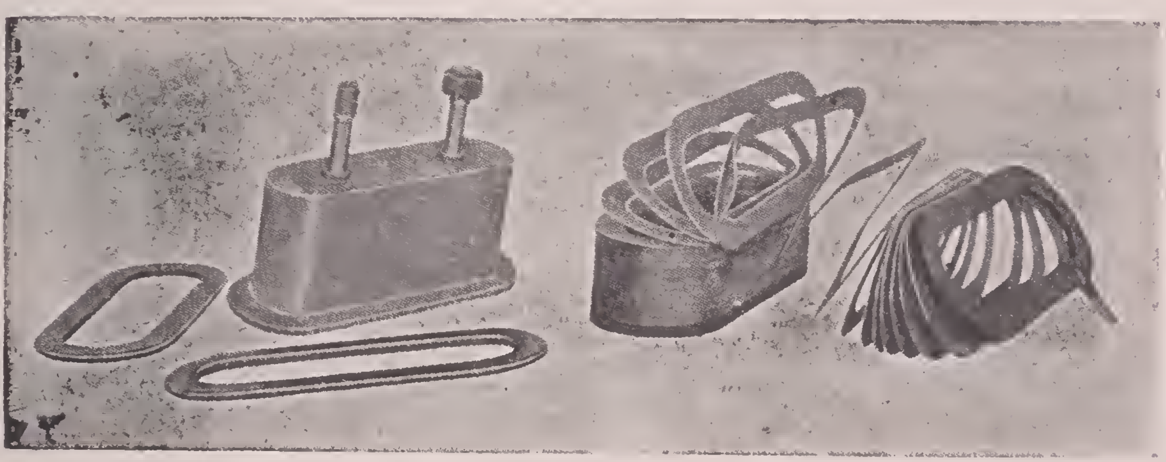

Fig. 199. Field Coil of Ribbon wound edgewise, with Laminated Magnet Core (on left).

This core has the pole piece cast with a hole, which is bored to a driving fit on the core.

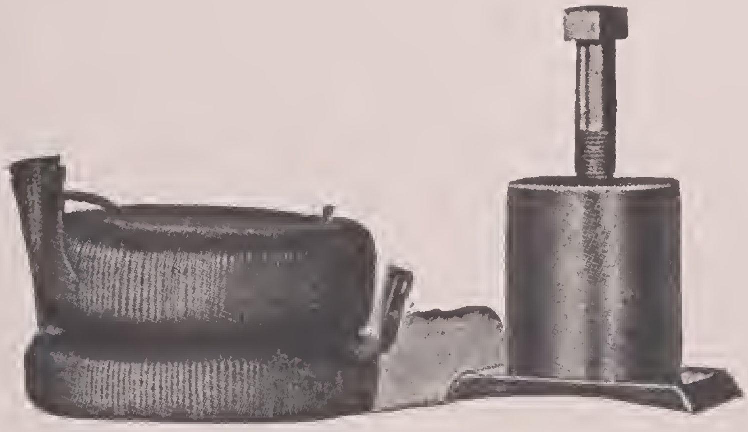

Fig. 200. Shunt and Series Coils ready to put on Core.

Fig. 201 shows a ring yoke with the field coils in place. Fig. 202 shows one of these fields ready to be bolted in place.

Bearings. Should be large; four to six times as long as the diameter of the shaft they contain; on account of the high speed. They are usually of the self-oiling type.

If there are collars on the shaft they should be arranged to allow the shaft to *float,* i. e., to move to and fro about 1-16 to 1-8 of an inch so as to distribute the oil in the bearings and to wear the commutator evenly. If there were no float, the brushes always touching on the same line around the commutator would wear grooves in the bars.

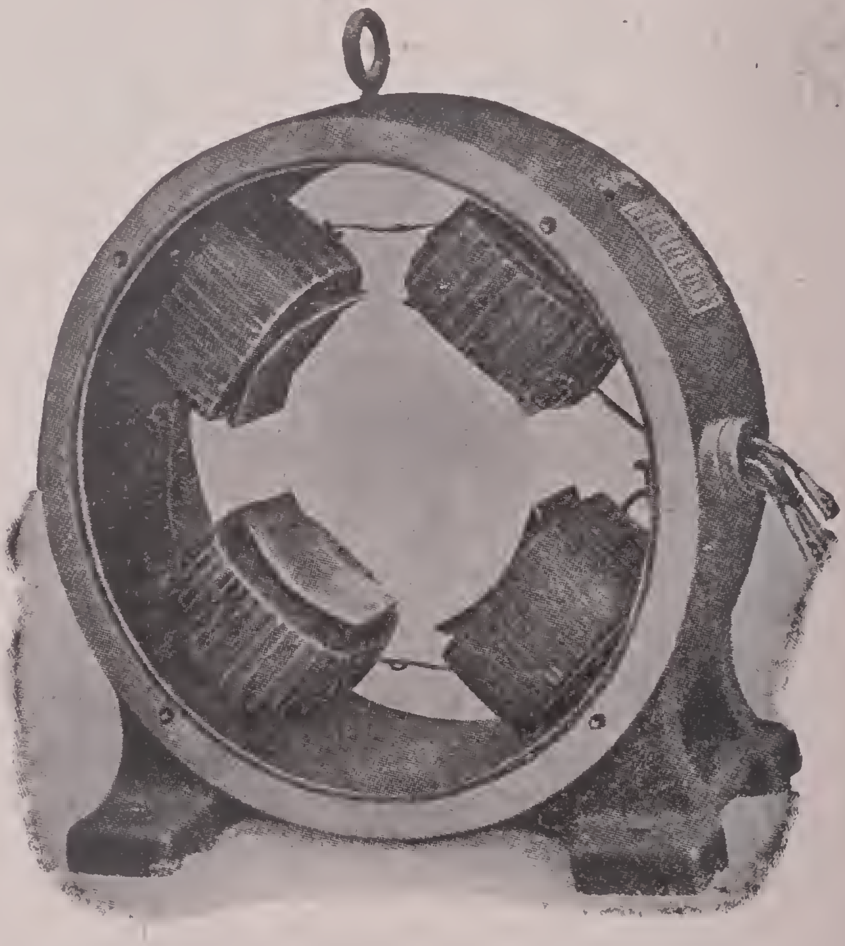

Fig. 201. Ring Yoke with Field Coils in place.

Rotary converters will not float of their own accord, so a magnetic or mechanical device is installed at one end of the shaft to compel a regular and even float.

At other end of shaft is often installed an "over speed" device to shut down power in case rotary "races."

Shafts are made thicker under the armature core than in the bearings; for the stress is greater out between the bearings, since the load acts with a lever arm.

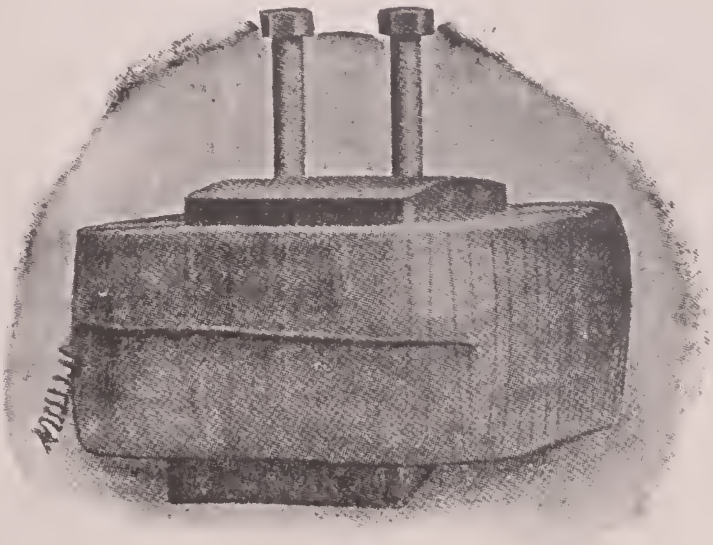

Fig. 202. Field Coil of Fig. 201 ready to be bolted into place.

They are made larger than in ordinary machinery because there is frequently a magnetic side pull due to unequal strength of the field magnets or the polar bore being eccentric with the shaft.

It is almost impossible to pull an armature out of the fields while current is passing through the field coils.

Core. The sheet iron body upon which the armature winding is placed.

Fig. 203 shows a toothed core into whose slots the armature winding is laid. The core is held firmly between two end plates, by bolts passing through tubes of insulation (usually fibre).

Generally the armature core is held by a *spider,* whose hub is turned and keywayed to receive the commutator hub. The spider hub is also bored, reamed and keywayed so as to form a *sleeve* or *quill,* which is slipped on the main shaft. In this case the complete armature may be removed for repairs without disturbing the commutator leads or getting core and commutator out of alignment.

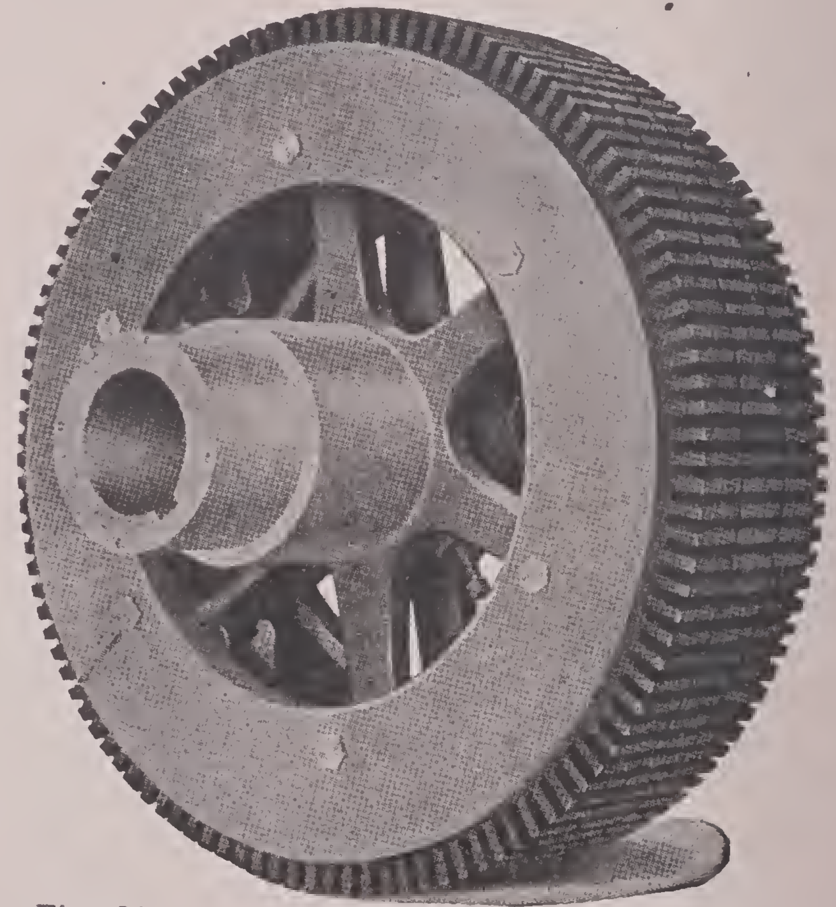

Fig. 203. Armature Spider and Toothed Core.

Fig. 203 shows this construction.

Hysteresis. When the iron core revolves it passes in succession under N and S poles and so the magnetism of the core is reversed.

All iron, no matter how soft, holds some *residual magnetism.* This "hanging on" of the magnetism is called *hysteresis.*

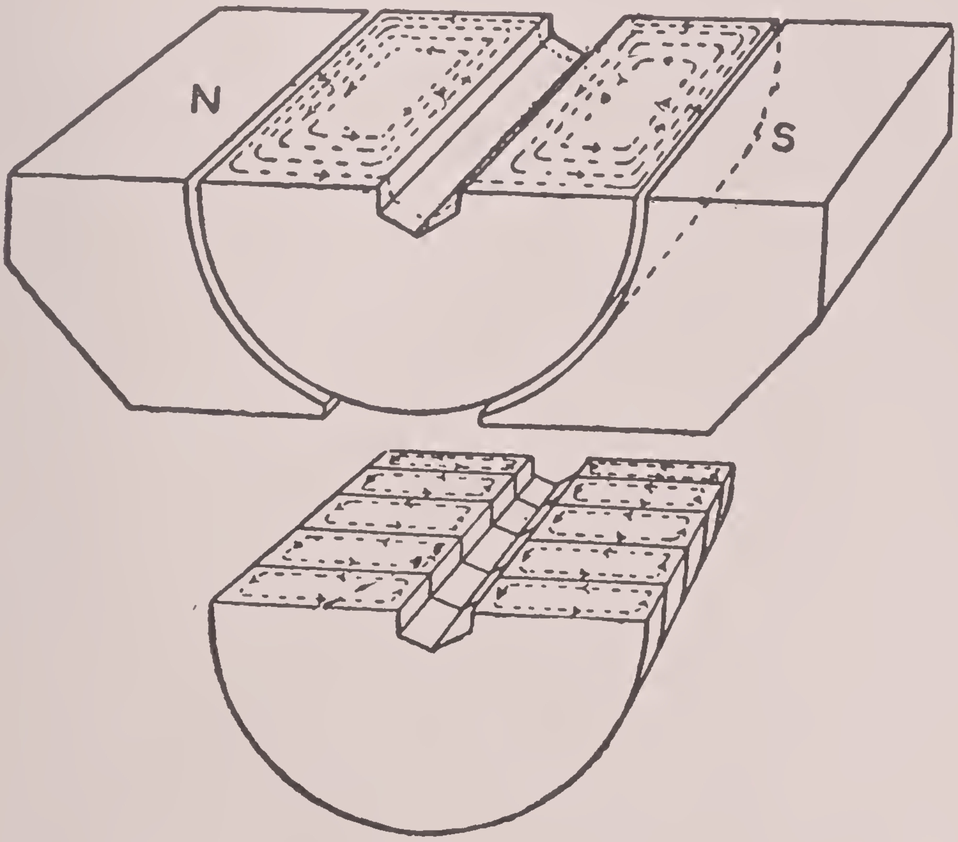

Fig. 204. Effect of Solid and Sheet Iron Construction on Eddy Currents.

Before the magnetism in the core can be reversed the residual magnetism must be wiped out. It takes about 1½ per cent. of the total power of a generator to do this work. This inevitable loss is made as low as possible by the use of a small quantity of the softest iron, worked at a low magnetic density. Increasing the quantity of magnetism per square inch, the speed of the machine or the pounds of iron in the core *all* increase the loss due to hysteresis.

Eddy currents, sometimes called Foucault currents. There must be E M F induced in the iron of the core, just the same as in the copper on the core. Were it not that the core is in sheets placed parallel to the flux, there would be a great waste of power sending current through a short thick body of iron. (Hence of low resistance.) The insulation of rust, etc., between the sheets forms a series of short, very thin conductors which are of high resistance, and hence the eddy currents are small. An increase of speed makes a great increase in the eddy currents. The usual loss due to them is about 1½ per cent. of the total power generated.

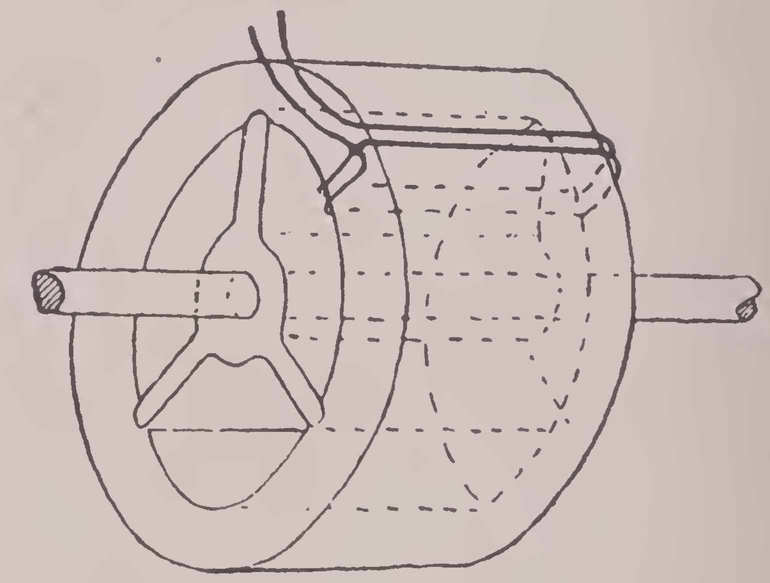

Fig. 205. Ring Winding.

Fig. 204 shows how the paths for eddy currents are made long and narrow by using sheet iron.

ARMATURE WINDINGS.

Ring. These windings are very simple to calculate but hard to place on the core. The method of winding is shown in Fig. 205.

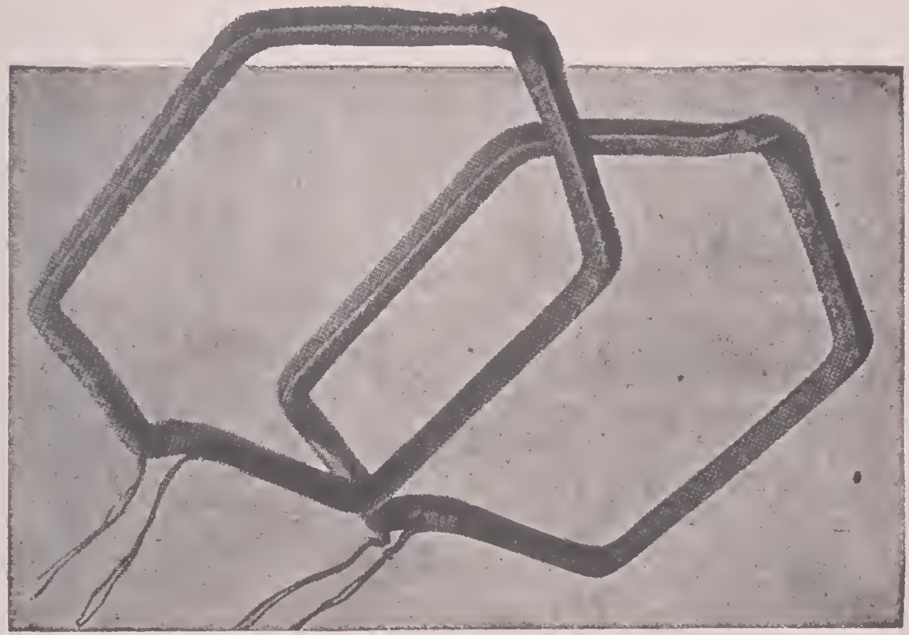

Fig. 206. Formed Armature Coil.

Drum. The double cotton covered wires are bent into shape; insulated with linen tape, baked and shellac varnished. A number of these *formed coils* (Fig. 206) are placed in the slots (Fig. 203) on the outer surface of the core (Fig. 207, also Fig. 208) and their ends soldered to the commutator bar lugs (Fig. 209).

Each slot contains two inductors. One side of a coil is in the bottom of a slot under a N-pole, and the other side in the top of a slot under a S-pole. This same slot has in its bottom a second coil, the outer side of which is in the top of a slot under a N-pole. The first men-

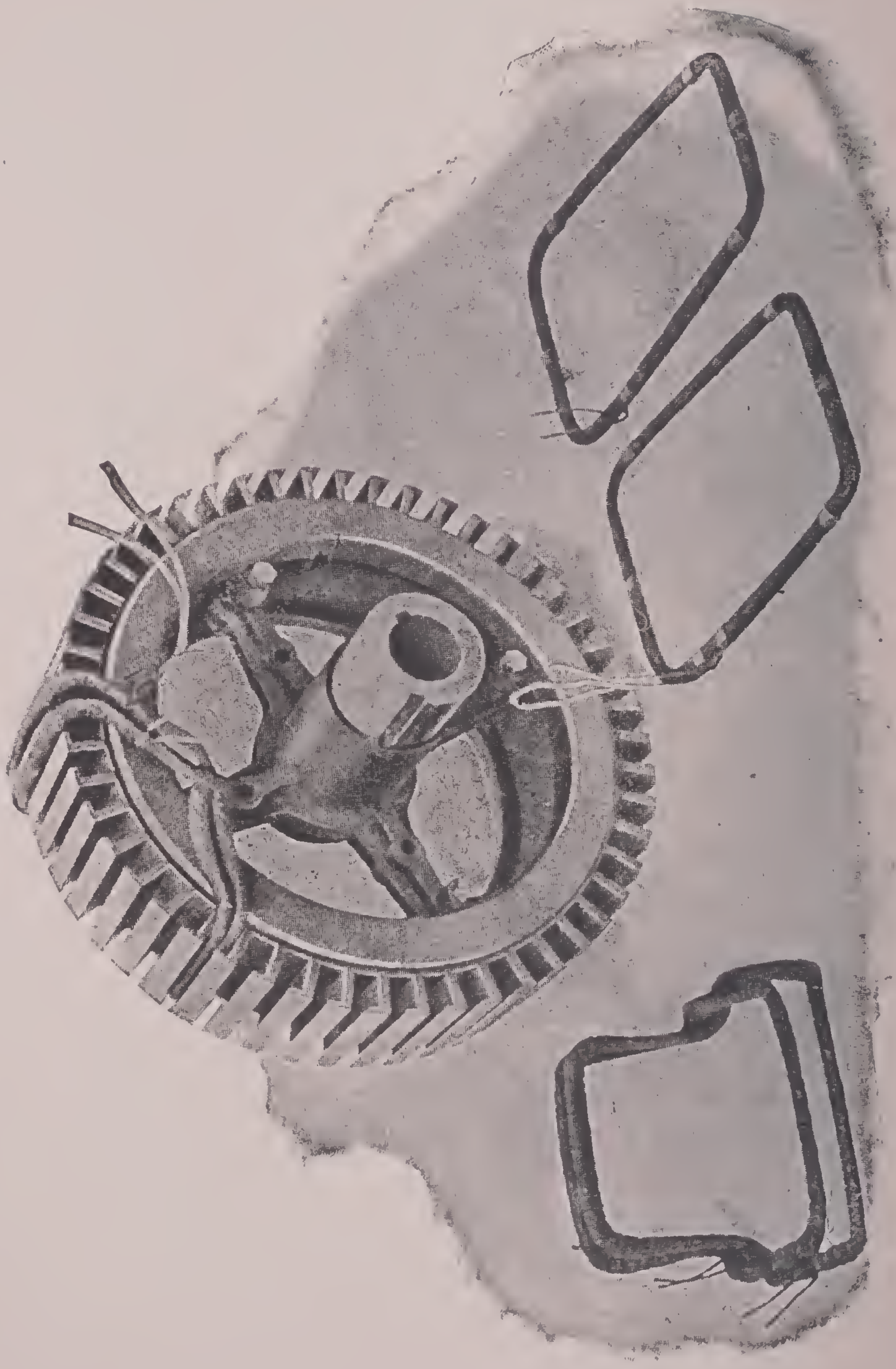

Fig. 207. Toothed Core with Formed Coil Winding.

tioned coil has its two ends connected to any two adjacent commutator bars, and the second coil is connected in the same manner to two bars on opposite side of commutator.

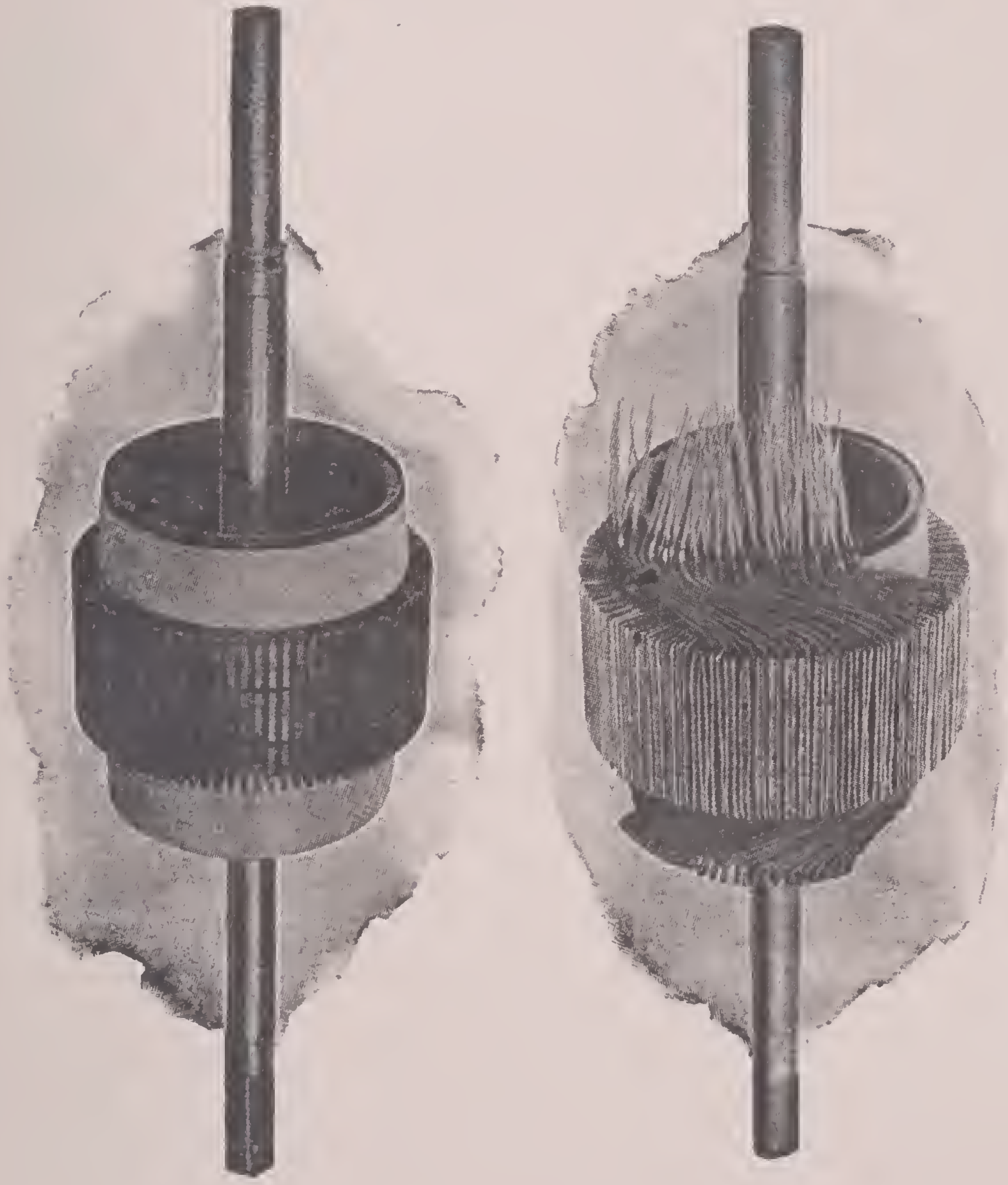

Fig. 208. Formed Coil Winding Incomplete and Completed.

Commutators. The peculiar shape of the bar (Fig. 210) makes it possible by the corresponding shape of the hub and washer to draw bar and insulation (mica) together tightly, both side, endwise and downwards, locking them absolutely in place by a nut bearing against the washer.

The hub is sometimes keyed to the shaft. This gives a chance to remove the commutator for repairs by unsoldering the leads from armature winding.

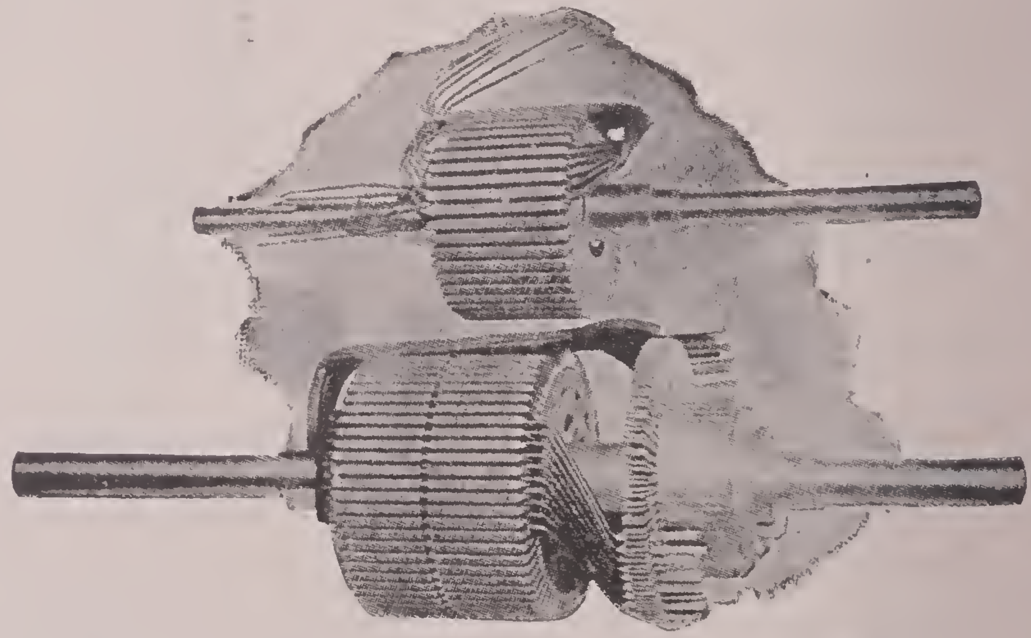

Fig. 209. Armature Winding connected to Commutator.

A complete armature, i. e., wound core and commutator, is shown in Fig. 211 on a quill ready to be put on axle or shaft.

The golden copper color of a new commutator soon changes to a uniformly rich dark mahogany brown, and its surface acquires a polish. The degree of the polish and uniformity of the color are indications of the success of operation. Any blackening of the bars or roughness of surface shows defects in machine or manner of operating.

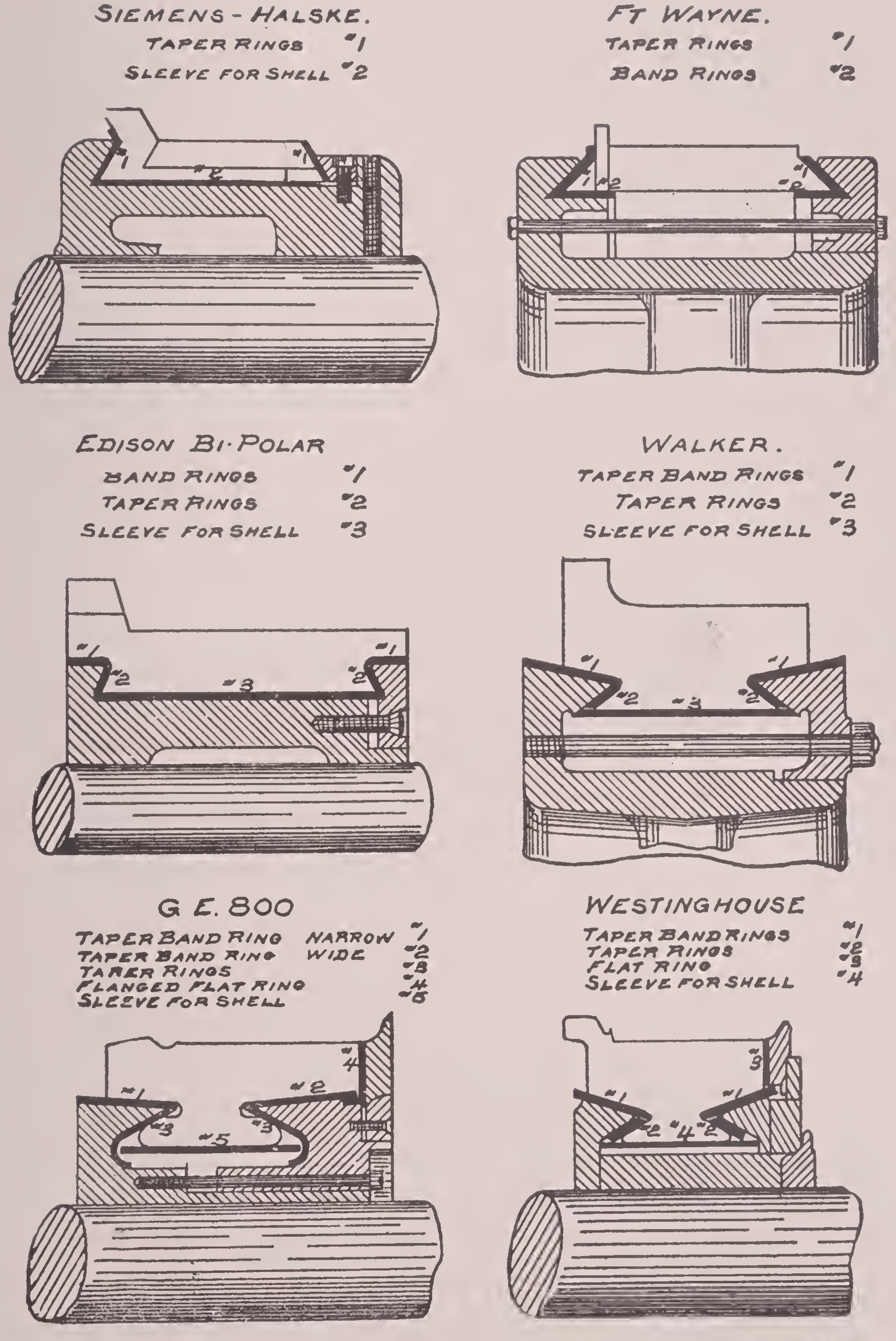

Fig. 210. Construction of Commutators Showing Hub, Mica and Bar.

Brushes of *copper* or brass in the form of sheets or folded gauze were formerly much used. In the modern machines with the losses reduced by clever designing, more current is drawn, a higher voltage generated and larger pole pieces used on the same sized armature.

The tendency of the brushes to spark is thereby increased and to offset this *high resistance* brushes must be used. Hence the use of carbon brushes is universal. Where the tendency to spark is not so great graphite brushes are used.

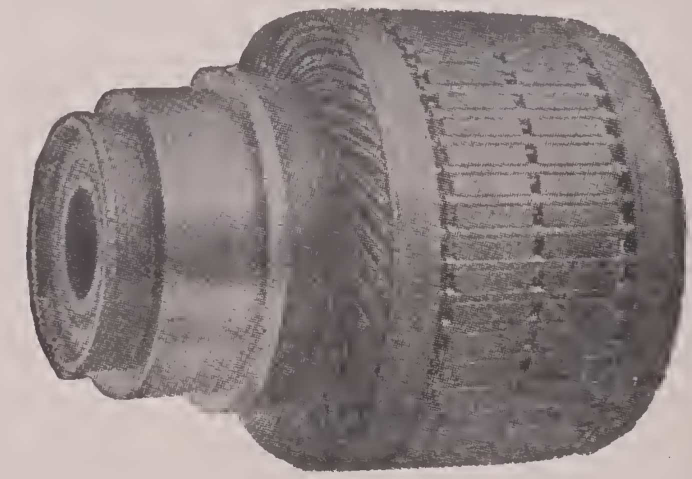

Fig. 211. Complete Armature.

For mechanical reasons copper rubbing on copper wears worse than carbon on copper. The abrasion between two surfaces of same material is generally worse than two different ones.

Dynamo brushes sometimes set at a slight angle from being perpendicular to the commutator as they always revolve in same direction.

For a motor the brushes are set radially against the commutator, for otherwise it could not be reversed without danger of breaking the brushes. They are pressed against the bars at about 1¼ lb. per square inch.

Sufficient area of carbon must be actually touching the commutator to collect the current at a density of 30 to 40 amperes per square inch.

This total area is divided up into small blocks about 1½x2 or 3 inches, and each has its own spring. This insures that at all times all of the brush surface is in contact with the commutator.

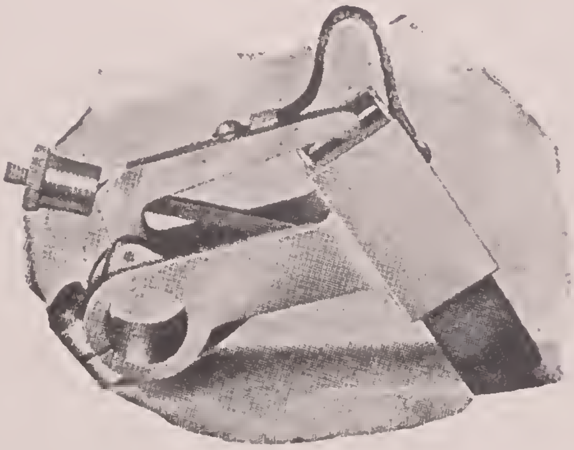

Fig. 212. Brush Holder.

Brush holders. The holders must clamp the brushes securely and press them straight against the commutator, as in Fig. 212. There must be sufficient area of contact between holder and brush, with good pressure so that the current may pass from brush to holder without producing a great C R loss.

The springs maintaining the pressure of the brush against the bars should not carry current, as they might heat and have their elasticity destroyed.

The current carrying capacity of the brush holders is often supplemented by *stranded* or *braided* conductors of copper, running from the brushes back to the brush holder cables. These are called "pigtails."

A set of brush holders is mounted on a brush holder arm or stud.

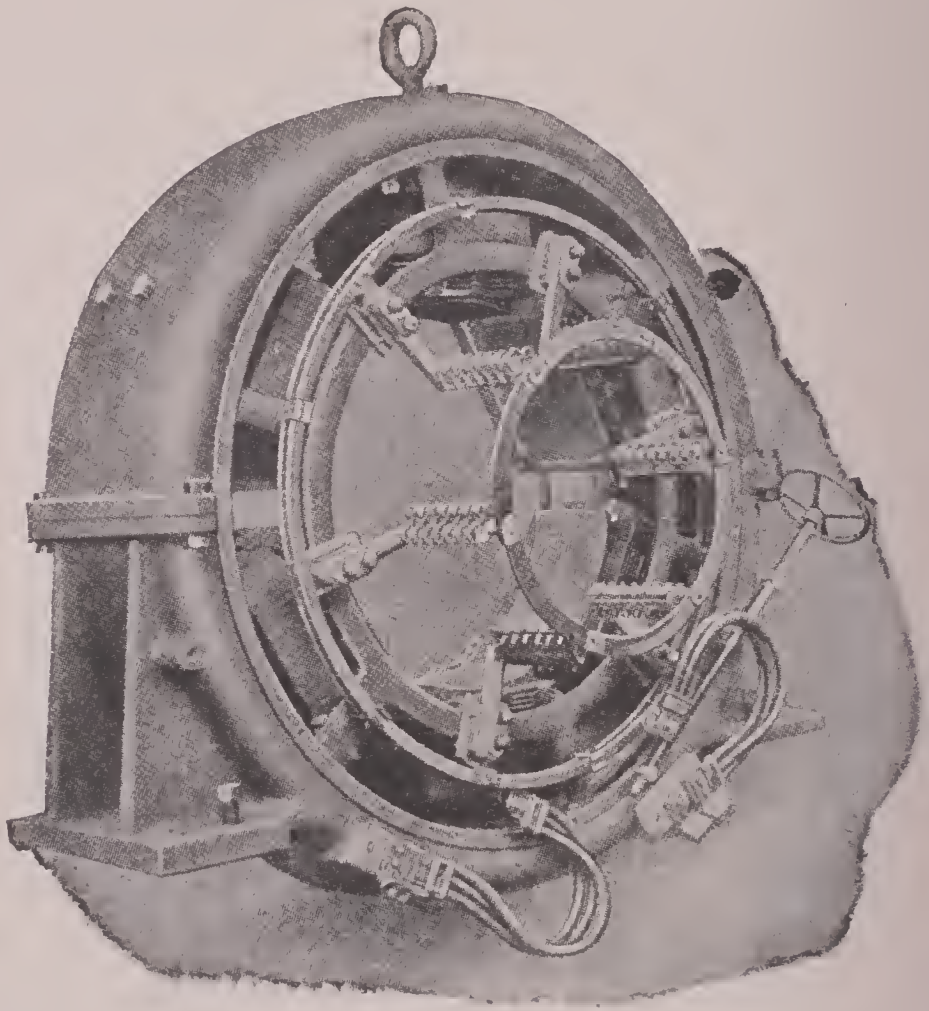

Fig. 213. Complete Brush Rigging on a D. C. Generator.

The brush holders on opposite sides of the commutator are not in the same plane, but by having one stud a little shorter than the other the brushes are *staggered.*

There is then no part of the commutator not worn by the brushes, and this together with the *float* of the shaft, keeps the commutator a perfectly smooth cylinder of slowly decreasing diameter as it wears.

An oval, barrel or spool-shaped commutator due to improper wear must be swung in a lathe and light cuts taken until it is again of the correct shape. This is called *turning down.*

The brush holder studs project from a ring which slides in grooved arms supported by the bearing pedestal or by the field frame. They can thus be moved simultaneously and set into the position of *no* or minimum sparking for full load, then locked in place. See Fig. 213.

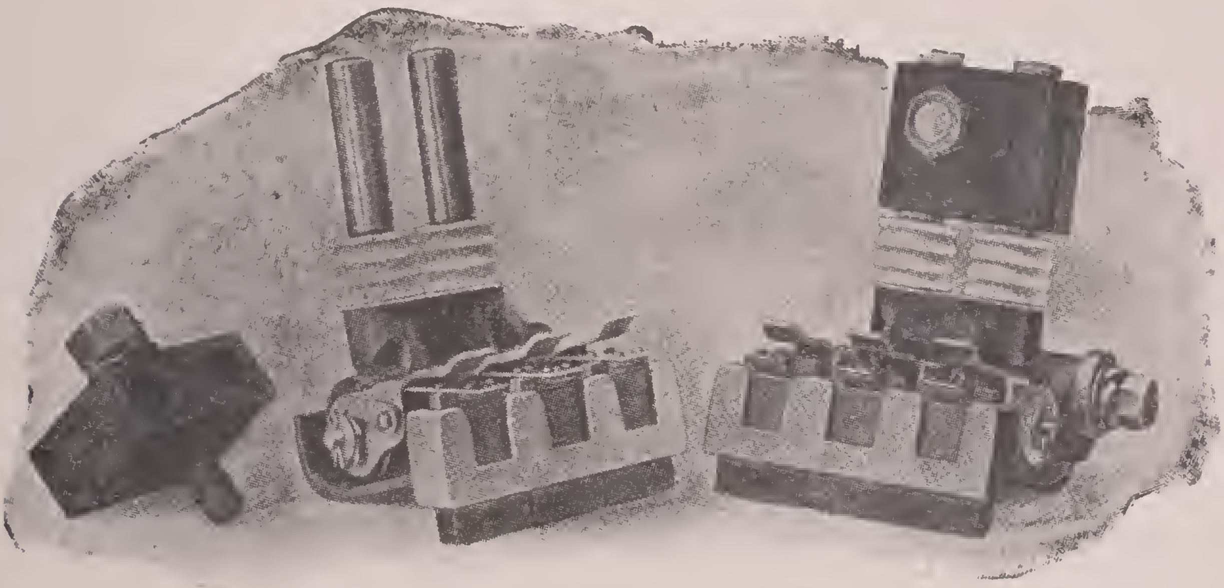

Fig. 214. Brush Holder on R. R. Motor.

On *railway motors* each holder stud is often clamped temporarily to the field frame or transoms of truck until the correct position is obtained, when they are bolted permanently directly against frame or transom.

The ability to change their position simultaneously is thus lost, but simplicity and reduction of number of parts and weight is obtained.

Figs. 214 and 215 show brush holders of railway motors.

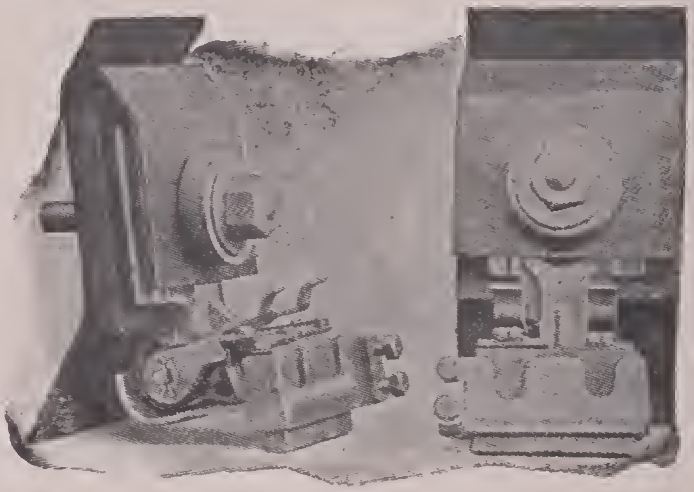

Fig. 215. Brush Holder on a R. R. Motor.

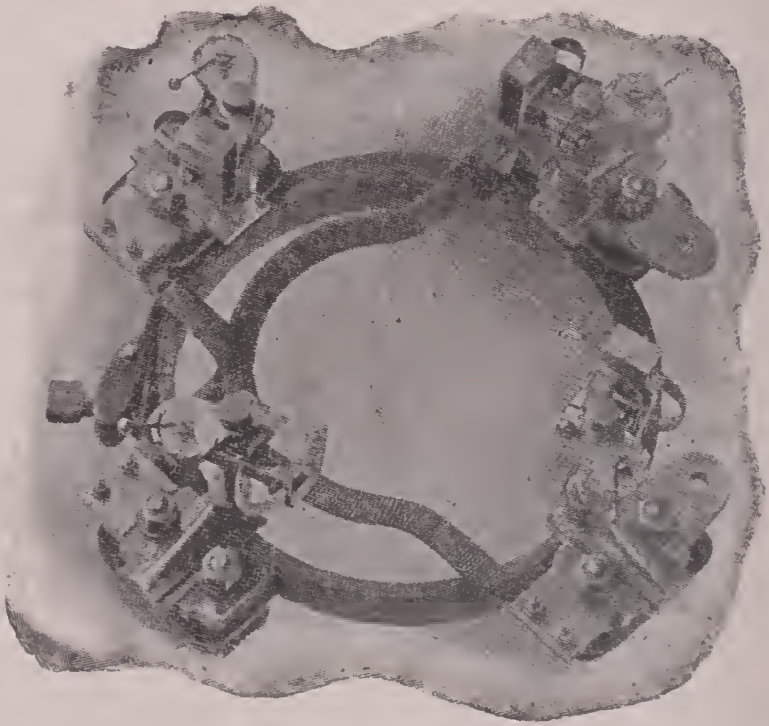

Fig. 216. Set of Brush Holders and Collecting Cables.

In Fig. 216 is shown an arrangement similar to Fig. 213. It is for a smaller dynamo and has no hand wheel to set brushes, but merely a set screw clamp shown on left side.

Field coils. The spools in which these coils are wound are made of brass or bronze, which being non-magnetic does not cause any leakage through its flanges.

Copper *strip* or *ribbon* is used on railway motors and fuller board or card board insulation between turns. Fig. 199.

To prevent injury to the windings they are usually wound with a layer of cord or tape. Fig. 217.

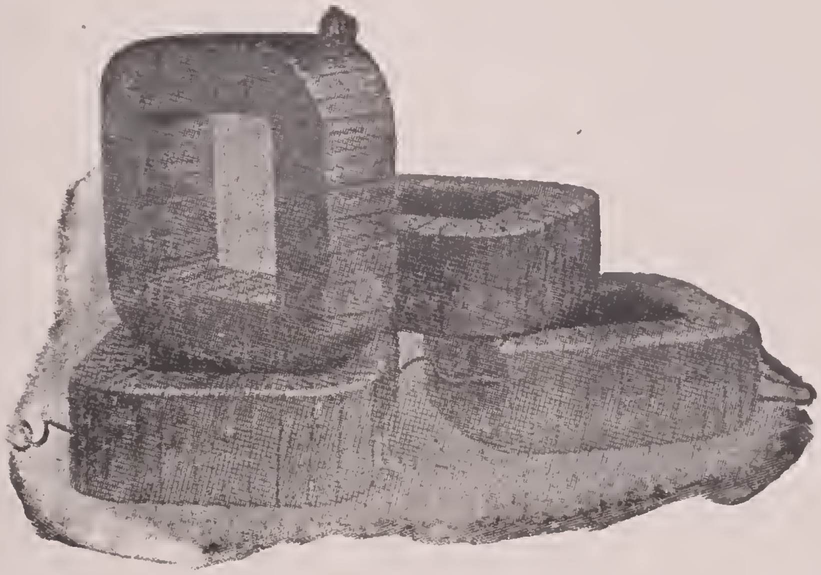

Fig. 217. Field Coils taped ready to place on Magnet Cores.

Fig. 218 is a railway motor field coil wound of strip copper and protected by a layer of cord. In motors where the field frame is not a shell completely enclosing the fields and armature protection is furnished to the coils by brass shells. These are riveted to the flanges of the field spool.

In the New York Central locomotive two hand holes are left, one containing the two terminals of the coil. Into these holes are poured a hot bituminous insulating compound, and when cool the covers are screwed on.

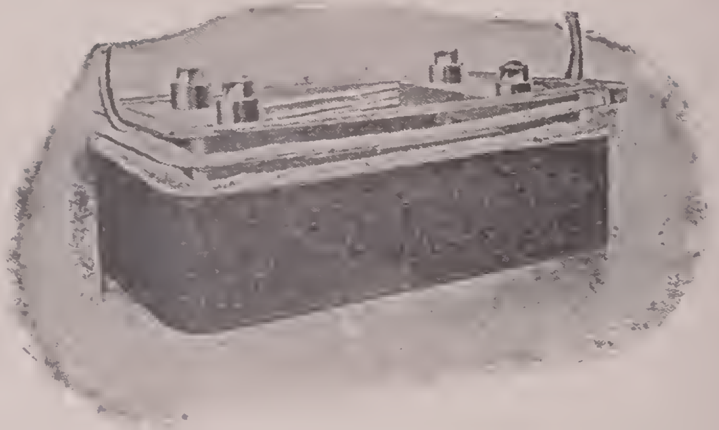

Fig. 218. Field Coil Wound with Strip Copper Insulated with Asbestos

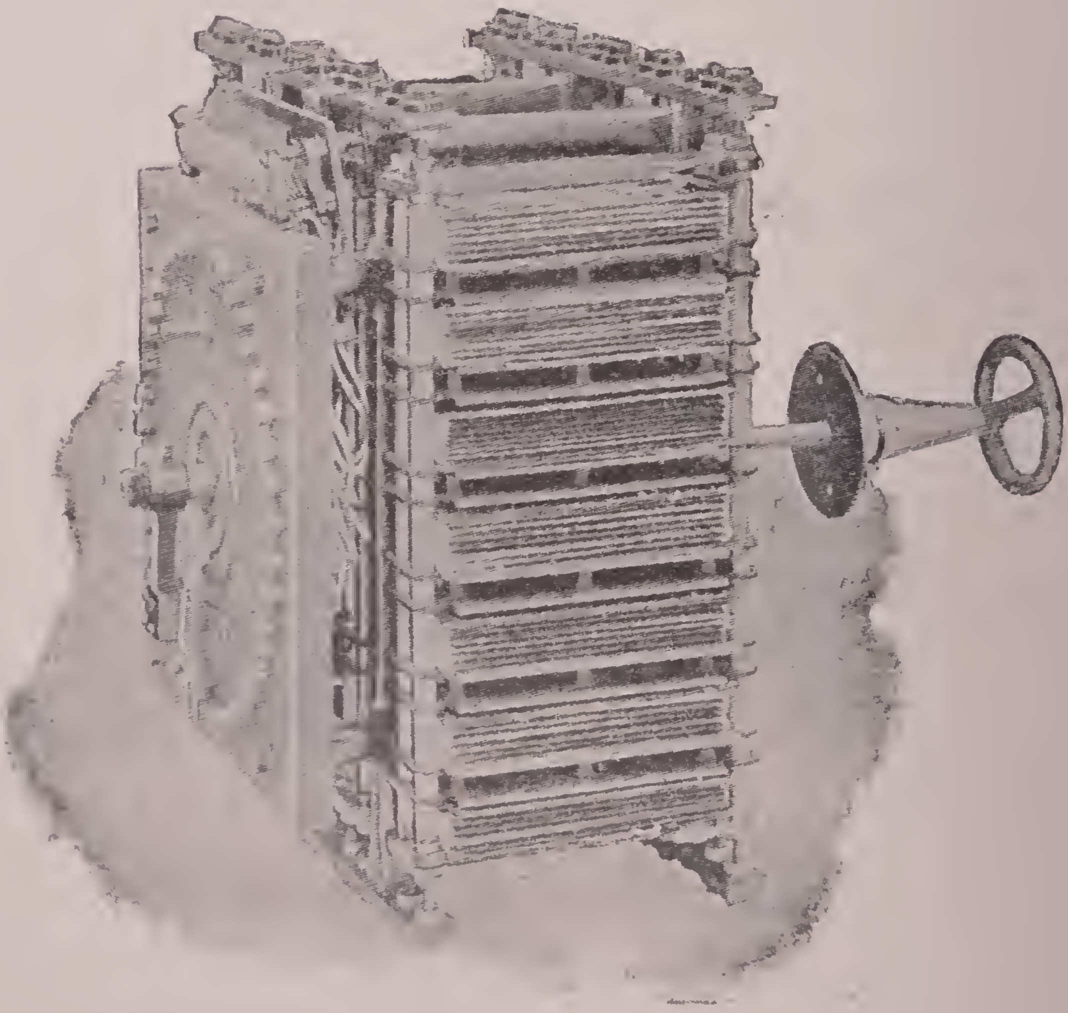

Fig. 219. Field Rheostat for Railway Generator.

From transom to transom under the armature is hung a curved piece of brass to protect it from flying stones and pieces of iron. Being perforated with 5-16 holes it does not interfere with the passage of air to cool the armature.

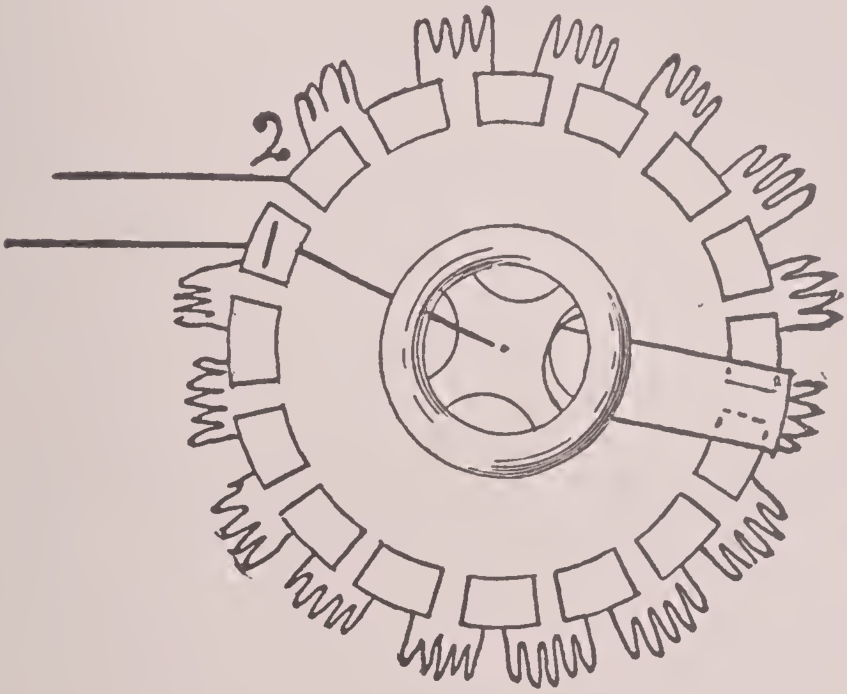

Fig. 220. Diagram of Field Rheostat.

Rheostat. In a dynamo an extra resistance, the value of which is about 25 per cent. of that of the fields, is placed in series with them, and by cutting more or less of this *field rheostat* in or out of the circuit, the field current is strengthened and weakened and the voltage of the generator increased or diminished.

At least part of this resistance is always in circuit and it is so designed as to size of wire and ventilation as to do this and not overheat.

Fig 219 shows a rheostat for a railway generator.

The handle projects through the switchboard, while the resistances made of cast iron are behind the panel. In Fig. 220 is shown the operation of such a rheostat. The current enters at 1 and goes through half of the resistance and out at 2. The amount of resistance in circuit being thus regulated by position of handle.

LESSON 27.

Railway Motors.

The main difference between ordinary and railway motors is compactness and inclosure.

The space that can be given to a motor on a truck is limited by the gauge of the rails and the size of the wheels. The gauge being fixed makes this dimension of the motor absolutely fixed; so that more room can only be obtained by using larger wheels. A 36 inch wheel gives none too much room to instal motors which are to be called on at times to give 200 H. P. The usual car wheel is 33 inches in diameter.

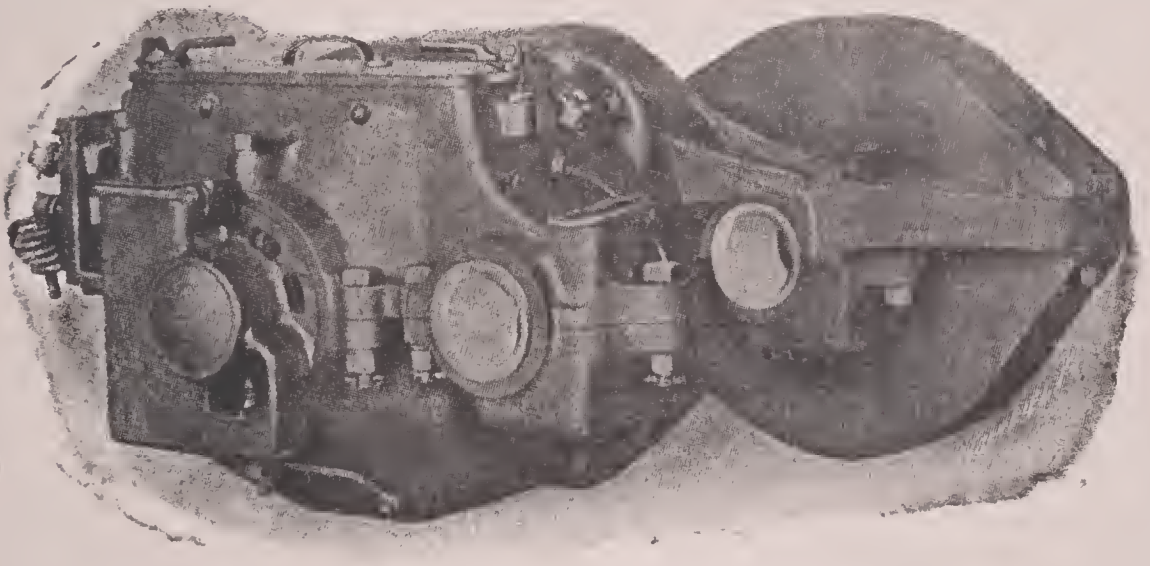

Fig. 221. D. C. Railway Motor, 40 H. P.

A railway motor must be completely inclosed to protect it from dust and flying stones.

Figs. 221 and 222 show inclosure of the motor and the gear case. The cast steel box which protects the motor also serves as the field yoke.

This motor has an armature 14 inches in diameter, the commutator is 10¼ inches in diameter and is composed of 111 bars. Motor with gears and gear case weighs 2730 pounds.

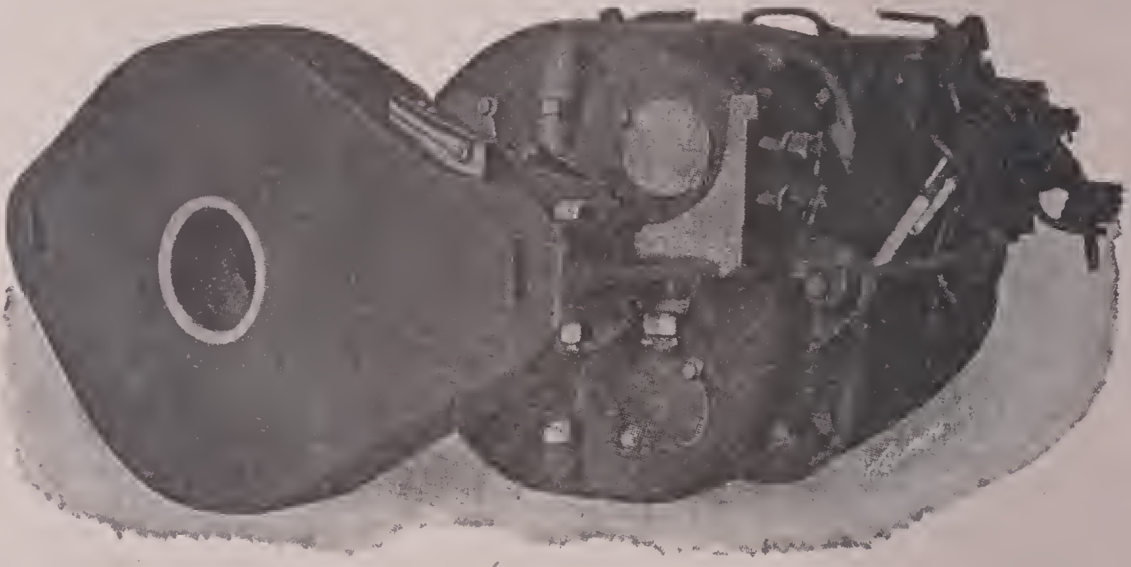

Fig. 222. Gear Case end of D. C. Railway Motor, 40 H. P.

The motor in Figs. 223 and 224 is a 60 H. P. motor built for A. C. work. The armature is 16 inches in diameter and commutator 12 inches in diameter, having 117 bars.

As shown it weighs 4000 lbs. and the gears and gear case weigh 500 lbs. more.

When mounted on 33 inch wheels there is 4⅜ inches clearance between bottom of motor and top of rail.

On account of the almost complete inclosure the armature must be designed to ventilate itself as much as is possible.

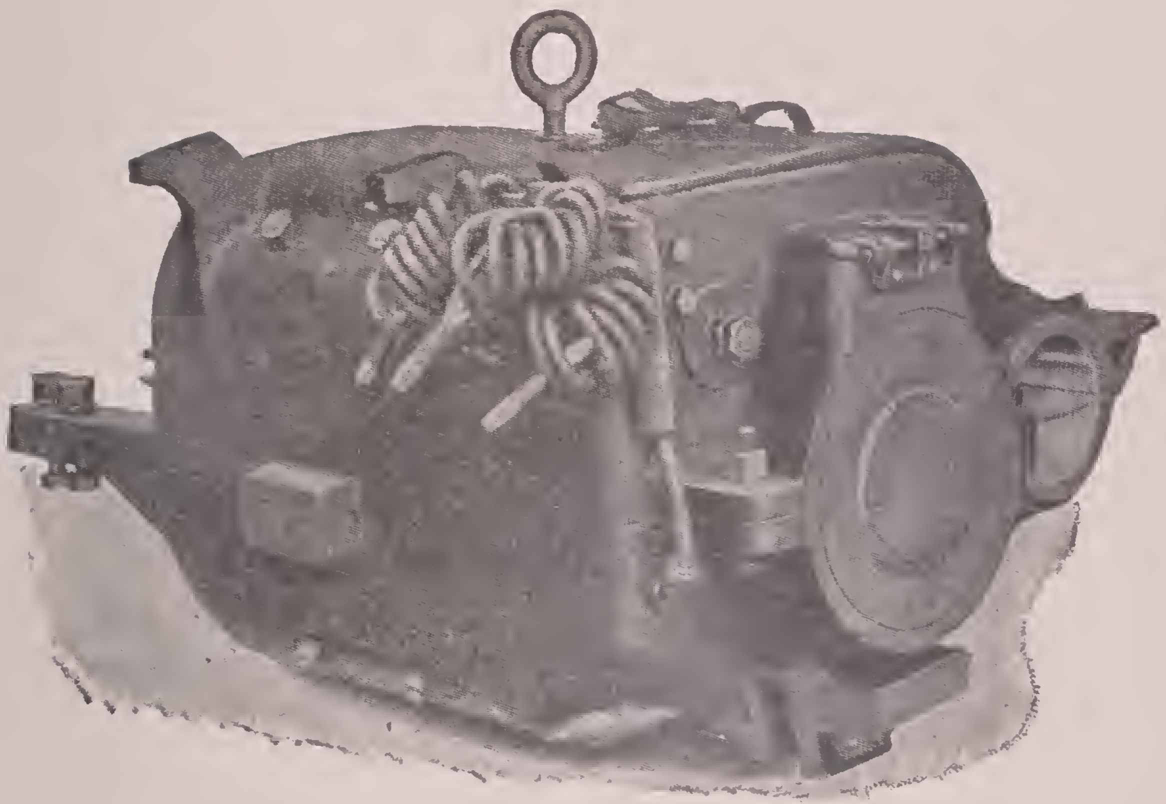

Fig. 223. Commutator end of A. C. Railway Motor, 60 H. P.

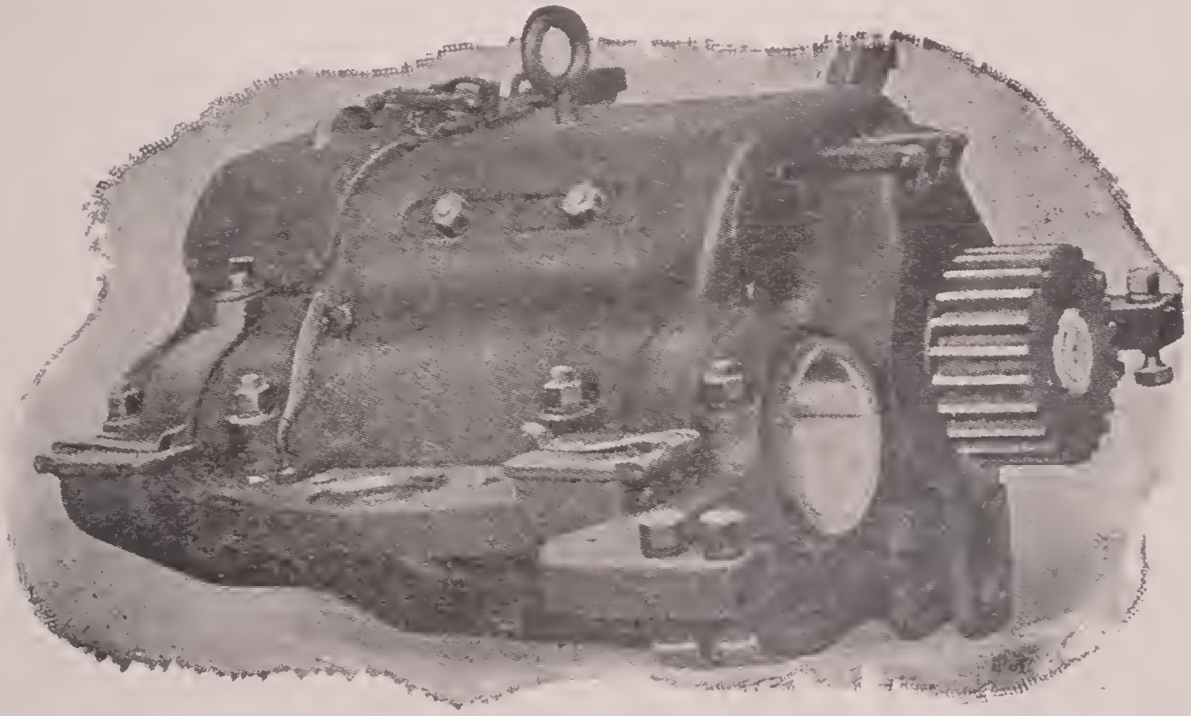

Fig. 224. Pinion end of Fig. 223.

The air is usually drawn in at the rear end (Fig. 225) and forced through windings and core by the shape of the spider, being discharged between commutator leads and against the pole pieces.

The case of a railway motor is usually split so that the lower half swings down or in a few instances the upper part of case can be swung up.

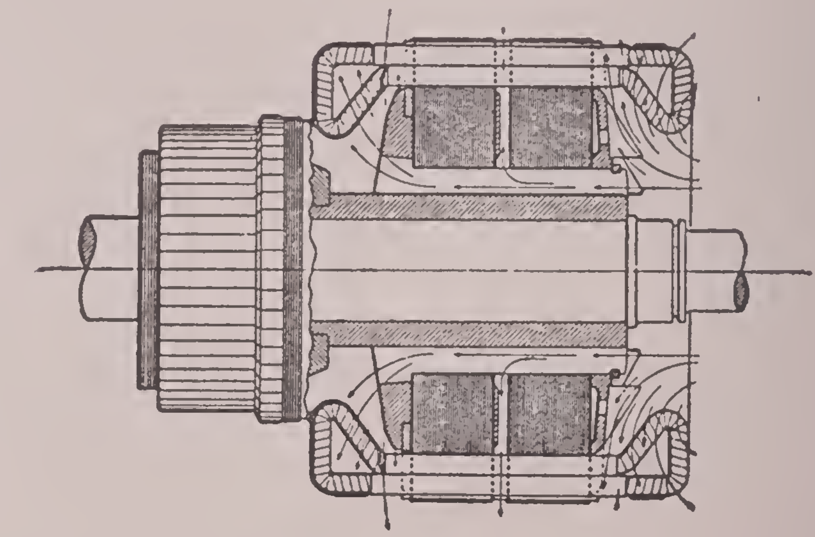

Fig. 225. Method of Ventilating Armature.

Fig. 226 shows the 40 H. P. motor of Fig. 221 with lower part of case down. By loosening the bearing bolts the armature can now be lowered into the pit and removed.

The pole piece and its field coil surrounding it are shown in the upper half of case.

The 60 H. P. motor of Fig. 223 is shown with upper part of case removed in Fig. 227. This is a four pole motor, two of them showing in the part removed. The brush holders also show in top part of upper case.

The four pole pieces are built up of soft steel punchings, riveted together between end plates of wrought iron and are held to the motor frame by bolts. The poles project radially inward at angles of 45° with the horizontal. Two bolts, secured by lock washers, hold each pole piece in place. They do not penetrate the pole face but terminate in heavy rivets inside the pole made for this purpose. A smooth and unbroken pole face is thus presented to the armature.

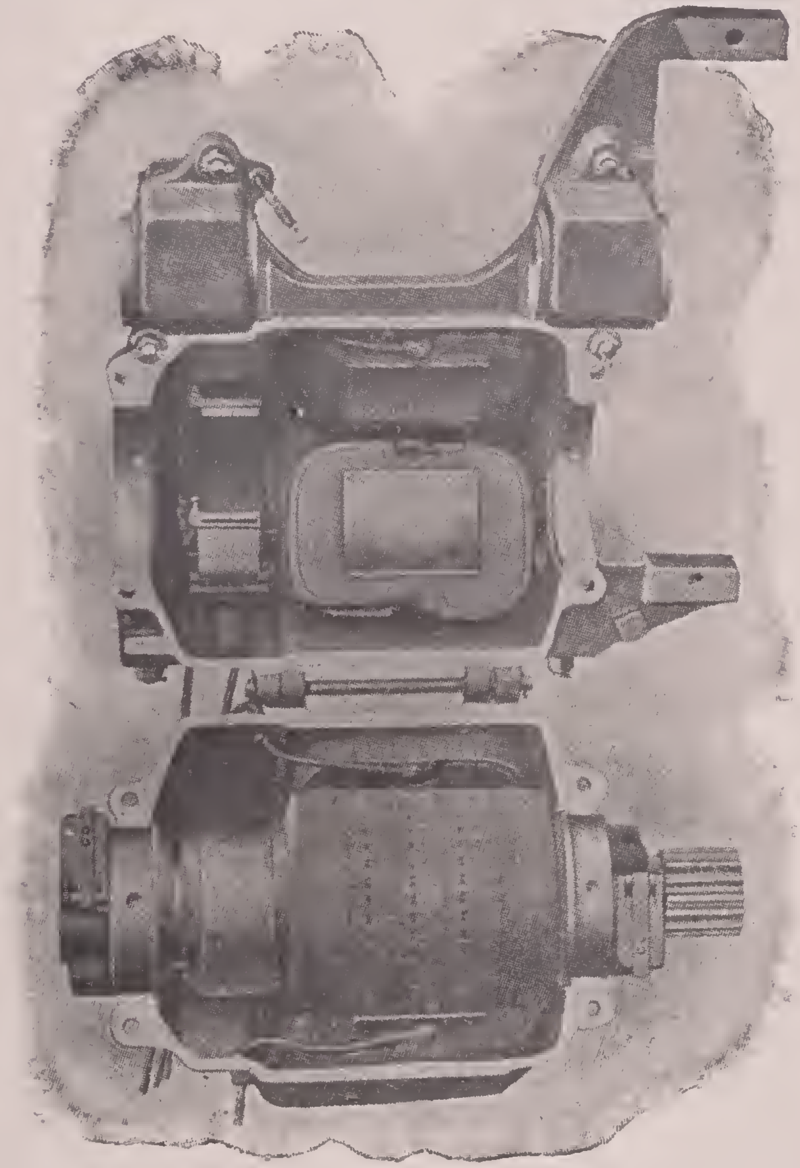

Fig. 226. Lower part of Case let down. Same motor as Fig. 221.

The poles are made with projecting tips, which properly distribute the magnetic field, and also serve to retain the field coils, which are held firmly in place by spring washers. The coils are wound with asbestos-covered wire. They are heavily taped and are treated with specially-prepared insulating compounds which render them practically moisture proof.

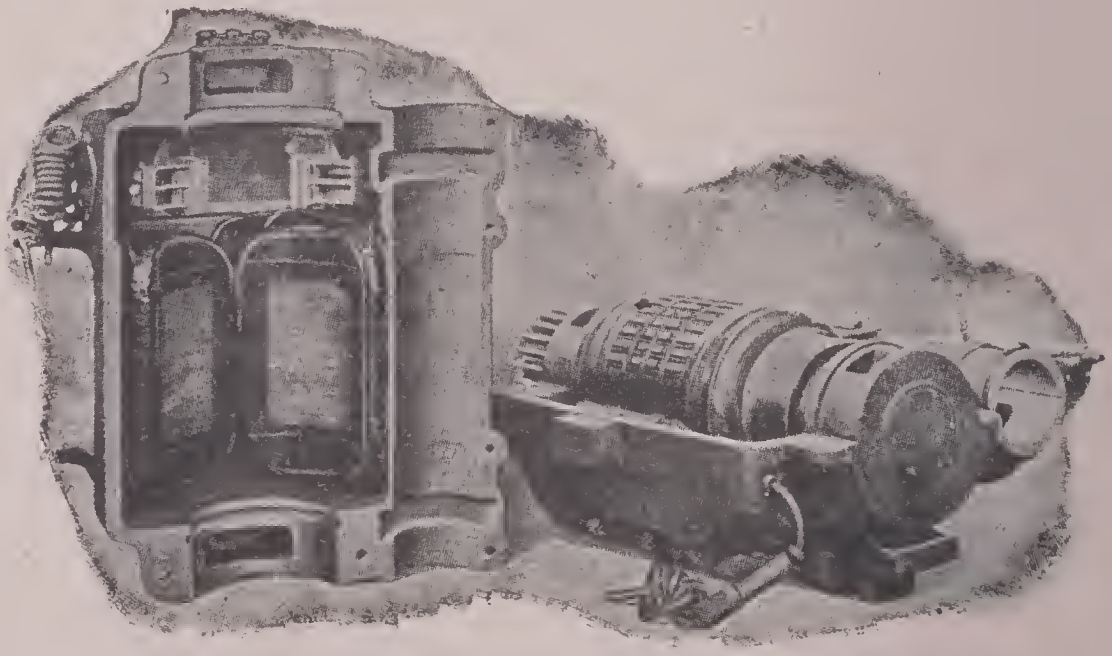

Fig. 227. Upper part of Case on Motor shown in Fig. 223 taken off.

Fig. 228 shows a 50 H. P. motor for A. C. with upper part of case raised.

There is in railway use to-day in this country practically only one motor, the series motor. This is used or D. C. or A. C. with very little difference in construction.

The armature winding for A. C. use being slightly different, for a separate winding is connected to the commutator bars called a preventive winding which prevents sparking.

In Europe the induction motor supplied with polyphase current is used considerably. The necessity for two or three line wires and double or triple trolleys, while not so very objectionable, has prevented its use in this country.

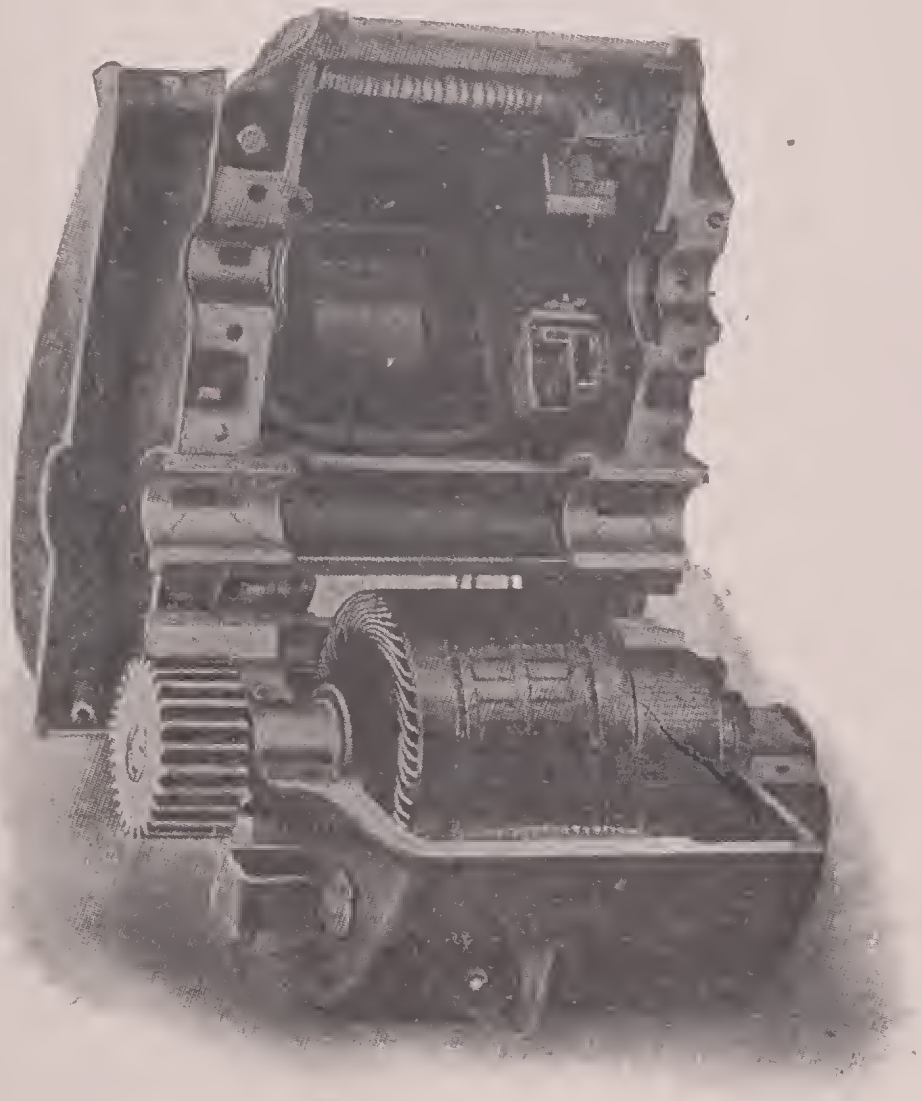

Fig. 228. Upper part of Case Raised on 50 H. P. A. C. Motor.

Box Frame Type of Motor. The rapid development of inter-urban railways created a demand for a motor of large capacity, which could be mounted under a car in a limited space. To meet this contingency was devel-

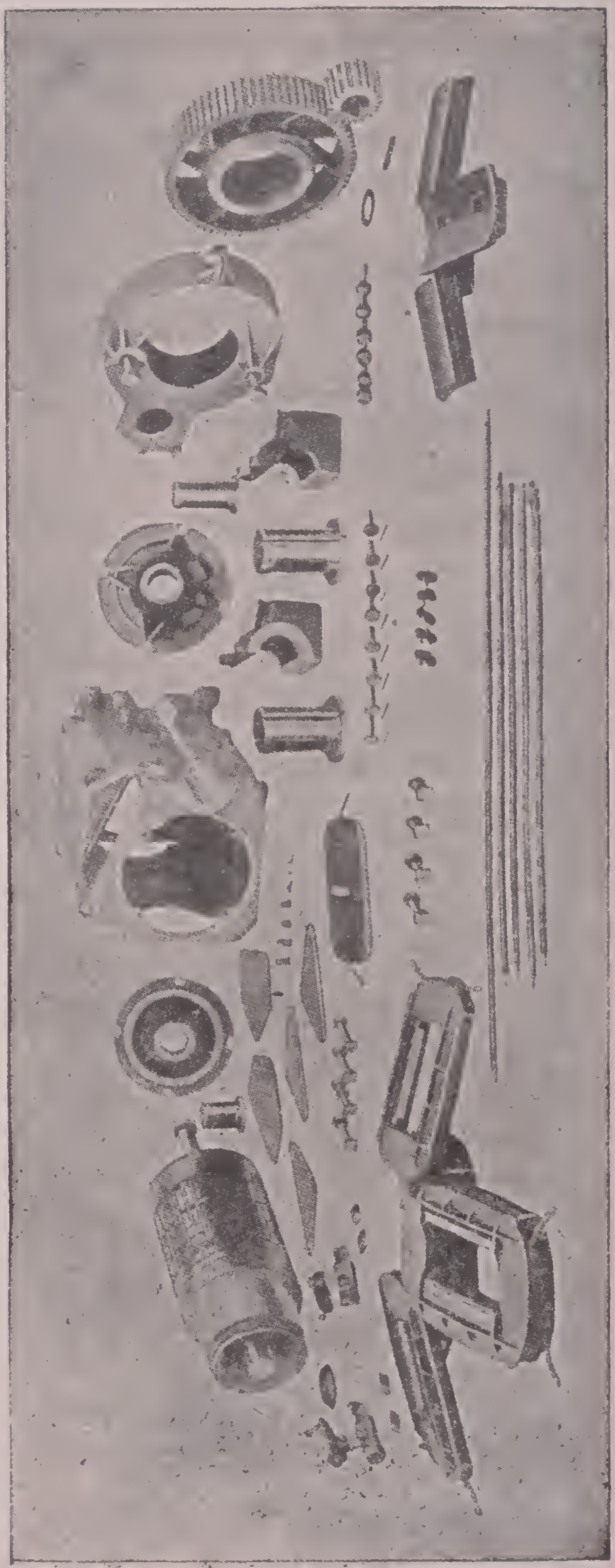

Fig. 229. Parts of a Box Frame Motor.

oped the box frame type of railway motor. This type of motor differs from the ordinary split frame motor, in that the magnet frame consists of a one-piece hollow casting, open at both ends. The armature is inserted in position from the side, being retained in place by end plates, which fasten to the field frame. One of the advantages of the box frame motor is the continuous magnetic circuit which exists throughout the frame. Additional advantages consist of a long commutator, ample room for ventilation, and absence of leakage of oil and water into the motor body. The armature may be removed from the motor frame at one side, obviating the necessity of employing a pit. Fig. 229 illustrates the various parts of the box frame type of motor ready for assembling. Fig. 230 shows a 125 H. P. motor of the box type.

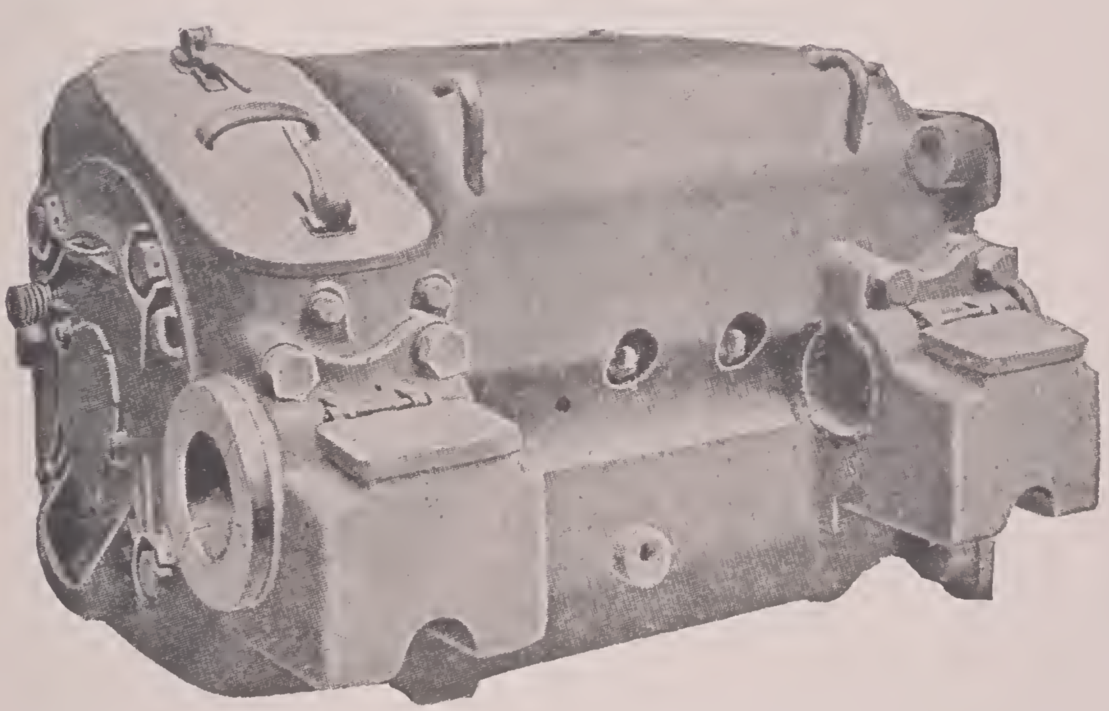

Fig. 230. 125 H. P. Box Frame Motor.

The Series Motor.

The series motor is a motor in which the same current goes through field and armature. It is usually a four pole motor only two of which have field coils, the other two being magnets because they are a part of the magnetic circuit. The poles are short and the coils broad and flat. The armatures are drum wound. When used on D. C. the magnet cores may be solid metal, but for A. C. they must be of sheet iron, as is also the *yoke.*

The only difficulty in operating such a series motor on A. C. circuits is the sparking. This is prevented by a resistance placed between each commutator bar and the one next to it, and lowering the voltage applied.

These resistances are wound in the armature slots and are called the preventive winding.

However, to make the motor operate with good efficiency on A. C. the field coils are actually imbedded in the iron of the magnet core, and the armature is made about 10% greater in diameter, revolving also at a greater number of revolutions per minute.

Such a motor takes only 250 volts A. C. against 500 volts D. C. It is larger and heavier than its mate designed to run on D. C.

If you will notice the air gap between pole pieces and armature it is less on the A. C. motor.

The D. C. series motor can exert a greater H. P. to start a train than the A. C. series motor; and the D. C. motor will get the train up to full speed quicker than the A. C.

It is a peculiar thing that all additions to the D. C. series motor in order to make it equally good as an A. C. motor also make it a better D. C. motor.

If a 200 H. P. motor giving 80% efficiency at 500 volts increased in size and weight by the additions and then run on 300 volts A. C. it will develop nearly 200 H. P., but if put back on D. C. again it will develop 275 H. P.

The fact is that a cheap, light D. C. series motor develops the same horse power as a more expensive heavier A. C. series motor.

Further an A. C. and D. C. motor of the same size and weight operate respectively on 225 and 550 volts and give 125 and 240 horse power.

The Induction Motor.

It has been known for a long time that there was a strong repulsion between the coils of a transformer, so that it was hardly a novelty when a transformer was made with the secondary built on the inside of a ring yoke and the primary on the outside of an armature core.

This transformer acted like a motor—in fact it was a motor. In order to give the motor good starting power it was wound for and served with three phase currents, and a resistance wound in with the primary so arranged as to be cut out after machine was up to speed.

The names armature and field will hardly apply to such a motor, so that the names Stator and Rotor have been adopted.

The Stator is the stationary winding whether connected to outside power or not.

The Rotor is the rotating part.

As usually built the stator consists of a winding producing a large number of poles, six and upwards, for the more poles the slower the rate of speed. The induction motor having an inherent tendency to revolve at tremendous speeds according to formula,

Velocity in rev. per min.=60×frequency÷number of pairs of poles,

it will be seen that many poles and low frequency are necessities.

The stator being served with two or three phase currents each pole is caused by the action of two or three coils. As the current rises and falls in these coils the magnetism grows and fades away. Hence the point of the stator where magnetism is greatest is continually moving around the stator.

Hence we say that it is a revolving field.

The stator winding is continuous and has no connection with rotor or outside power. The current in it is induced by the transformer actions of the rotor.

The rotor is usually a slotted core of sheet iron in each of which is part of a single conductor coil. These coils are all connected together at one end and in groups of two or three; are connected to slip rings through which current is carried to the rotor windings.

Sometimes the ends of the windings project out of the slots and have German silver pieces attached to them, a ring being arranged to slide along the German silver pieces. To start motor the ring is slid out so that the winding has a high resistance. When up to speed the ring is slid in and cuts out the resistance, leaving only the regular winding in circuit.

For railway work the coils are usually connected directly to the slip rings and the resistances inserted in the lead going to the brush. Care must be taken to have these resistances exactly equal and to have them reduced simultaneously until cut out altogether.

These motors are doing excellent work in Europe, but to an American the induction motor equipped locomotive or car seems a huge joke.

In the first place an induction motor runs at one speed and only one speed. After train is started it runs at 20, 30 or 40 miles per hour as steady as a clock, up hills, down hills.

In order to get different speeds four motors are often used, all being used at low speeds and only two of them for high speeds. This is so because if the current from one stator is fed into next rotor, the result is the same as if one motor of many poles was being used and the speed is slow, when each motor is being worked independently the result is same as one motor of few poles and the speed is high.

In certain cases two motors having a different number of poles are used. For slow speed, the rotor of one feeds stator of second. For next highest speed the motor with larger number of poles is used alone; and for highest speed the motor with fewest poles is used alone.

Induction motors have the peculiar property on down grades of feeding power back into the trolley and thus assisting the power house to run other trains up the hills.

Relation of Flux in Armature and Field of Motor.

It has caused much surprise to the unthinking that a series motor should continue to revolve when switched from D. C. to A. C.

Consider the diagram in Fig. 231. Suppose the current to flow so that the field polarities are as marked. The armature polarities will be such that near the upper brush is a N-pole and near the under brush a S-pole, these poles being directly opposite each other. The top pole of armature being N, the N-field magnet will push and the S-field magnet pull, so that armature will begin to rotate in clock-wise direction.

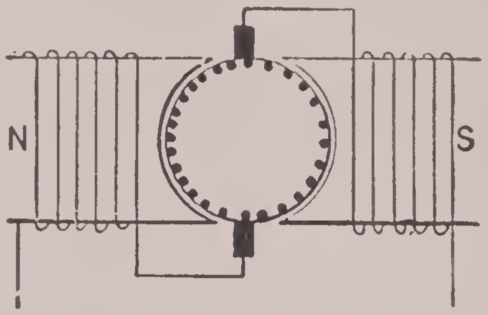

Fig. 231. Diagram of Circuits in Series Motor.

Suddenly reverse the current. All the polarities will change, but motor will continue to revolve in same direction.

The left magnet is now S, the top of armature S, and the right field magnet is N; hence the push and pull of fields on armature is same as before. Hence a series motor will run on A. C. circuits, for while the polarities keep changing the turning effort or torque is always exerted in some direction.

Reversing a Motor. To reverse the direction of a motor, you must change the direction of the current through the fields or through the armature, but not through both. Interchanging the two main leads to a motor will not affect its direction of rotation. Remember that reversing the current reverses the polarity.

Direction of Rotation of a Motor. In Figs. 232, 233 and 234, A represents the armature core and S. N. the pole faces. The windings of armature and fields are indicated by circles, being marked + when current flows toward observer, and — when it flows away from him. The blank circles carry no current.

In Fig. 232 the flux is due to the field coils alone and the polarity is indicated by the letters S. and N.

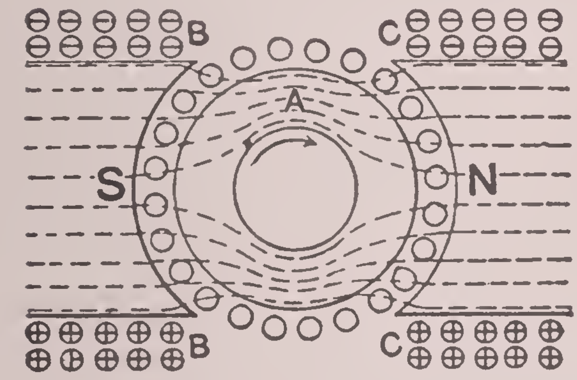

Fig. 232. Field Flux Alone.

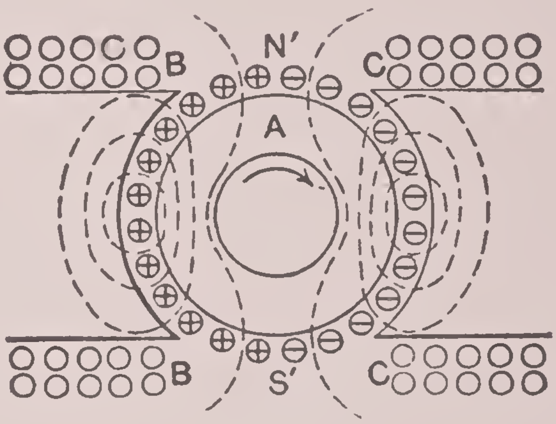

Fig. 233. Armature Flux Alone.

In Fig. 233 we have the flux due to the armature current alone, when the machine is driven as a generator in direction as shown by arrow, producing poles at N′ and S′.

Instead of letting the machine supply electricity, furnish current to it; flowing through armature and fields at the same time and in the same direction as before. The polarities will remain unchanged and the armature will begin to revolve as *a series motor, in the opposite direction to that in which it was driven as a series dynamo.*

A shunt motor will rotate in same direction as a motor or as a generator because when current is supplied to terminals of machine it runs through field in same direction as before, but through armature in opposite direction. Refer to Fig. 196.

Sparkless Reversing. The conditions when current flows through an ordinary series motor ready to operate in a direction opposite to the indication of the arrow are shown in Fig. 234.

The brushes are, of course, at N′ and S′ but since they should be in a line at a right angle to the general direction of the flux, it is evident that they are *not* at the place for sparkless operation.

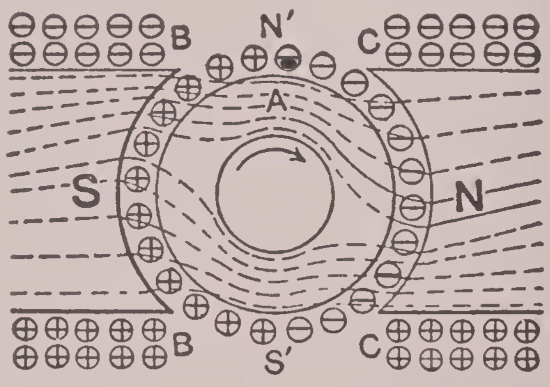

Fig. 234. Combined Field and Armature **Fluxes.**

The magnetic flux takes the peculiar direction shown in Fig. 234 due to the interaction of the field and armature fluxes.

Looking back at Figs. 134 and 135 you will see that it is natural that when these fluxes occur at the same time, the N′ would attract the S flux, and the S′ pull the N flux so that the resultant or machine flux would be as in Fig. 234.

The stronger the armature flux and the weaker the field flux the more the machine flux is twisted.

If the armature is weak and the field very strong the effect of the armature will be very slight, or as we say "the *armature reaction* is small," and the machine flux will look like Fig. 232.

In this case the brushes at N′ and S′ are in the proper place for sparkless operation.

If the flux were like Fig. 234 upon reversal of the armature current the flux would twist in the other direction, but if the flux were like Fig. 232 the reversal has no effect.

The machine flux of all railroad motors is like Fig. 232, so that they may be reversed without any change of brushes.

LESSON 28.

ALTERNATORS.

The main difference already noticed between the D. C. generator and the A. C. generator, called for shortness' sake an alternator, is that one has a commutator and the other a collector.

There are, however, differences in construction which must be noticed.

The highest voltage for which D. C. generators are wound is 1200, this being the lowest voltage for which alternators are wound, while for railroad work 11000 is the usual and 22000 not uncommon.

This makes the problem of proper insulation for A. C. armatures more difficult. To make the work easier, instead of having the field stationary and armature revolve as in most D. C. generators, in alternators the field revolves and the armature is stationary.

The field is fed with D. C. at 250 volts pressure and is easy to insulate even though subjected to the mechanical strains of rapid motion and the lack of plenty of space.

The armature being stationary there are no mechanical strains, also weight being no objection plenty of space can be given to insulation.

This type of construction is shown in Fig. 235 and 236. Fig. 235 shows a revolving field of 18 pairs of poles or 36 poles. Current is led in through a collector. This field revolves inside of the stationary armature (Fig. 236) whose windings are fully exposed to the cooling effect of the air. This armature needs no collector, for the terminals of the winding are attached to leads which come out of the base at one side. (In the Fig. at right side.)

Ventilation of the field and armature is accomplished by means of air ducts as is well shown in Fig. 237.

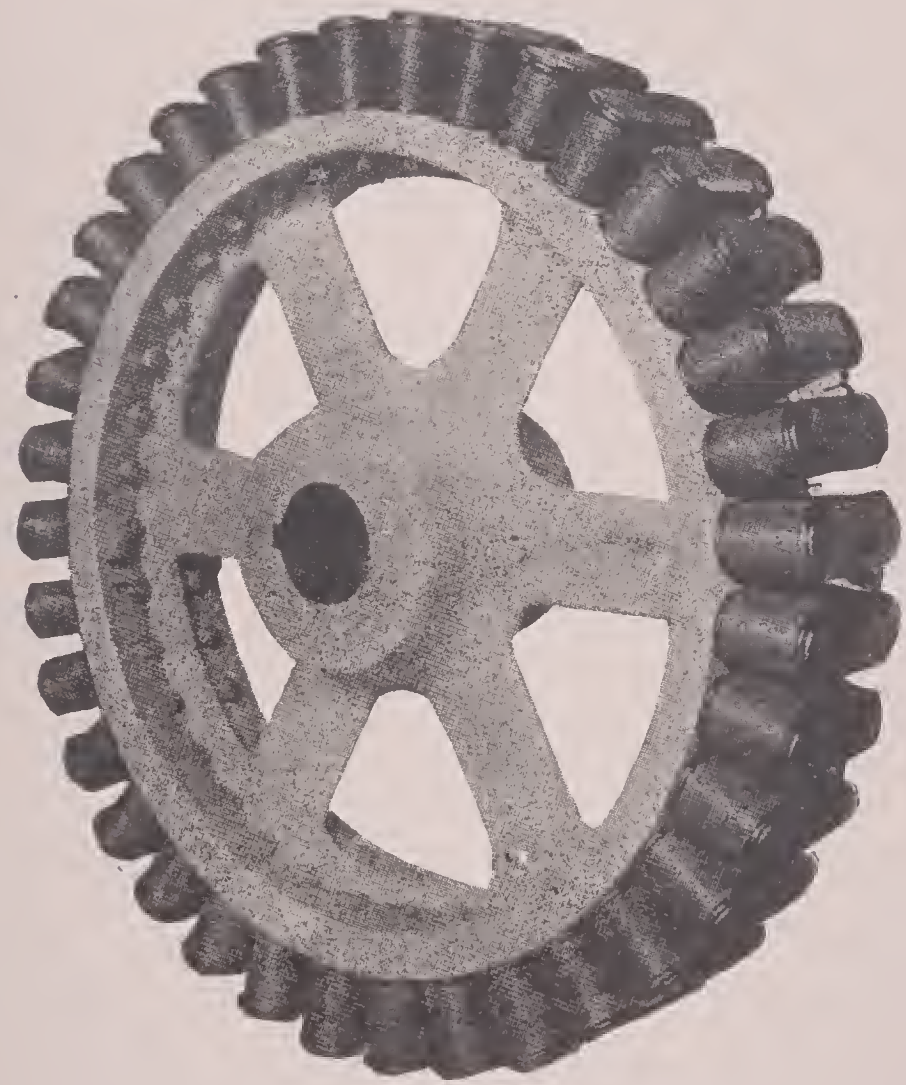

Fig. 235. Revolving Field of Alternator.

The magnetism in all armatures fluctuates and reverses in polarity as it passes or is passed by the poles; but in alternators these reversals of magnetic polarity are much more rapid than in D. C. machines.

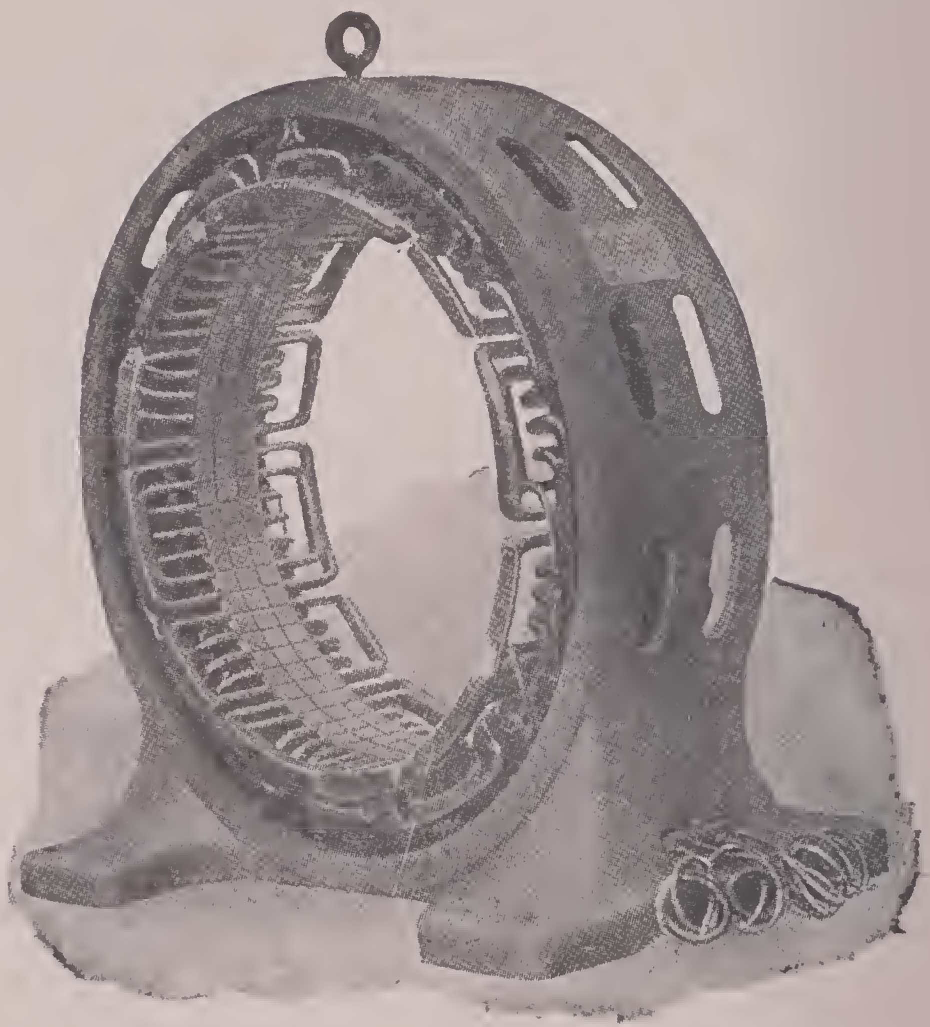

Fig. 236. Stationary Armature of Alternator.

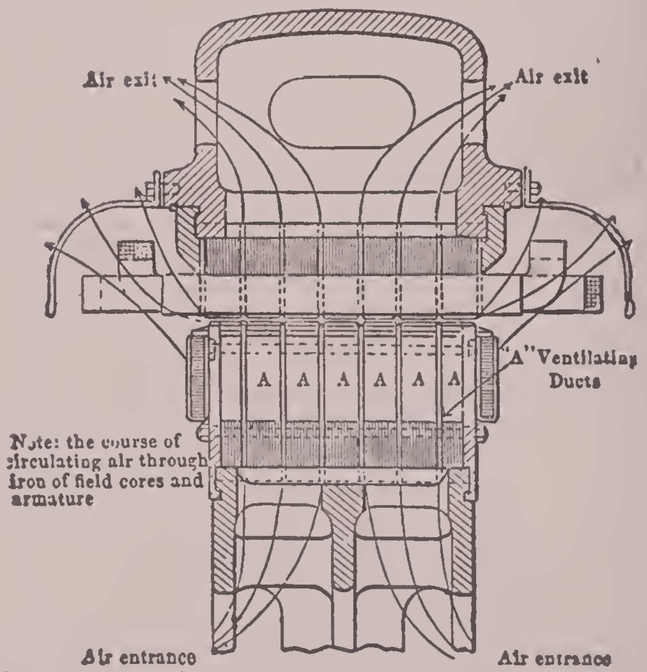
Air exit
Air exit
A A A A A A
"A" Ventilating Ducts
Note: the course of circulating air through iron of field cores and armature
Air entrance
Air entrance

Fig. 237. Method of Ventilating Alternator with Revolving Field and Stationary Armature.

To prevent the waste of power necessary to magnetize and demagnetize solid iron at such a rapid rate, not only is the armature iron laminated but the magnet cores also.

Fig. 238 shows such a magnet core and Fig. 239 shows the way these cores are attached to the magnet frame or yoke.

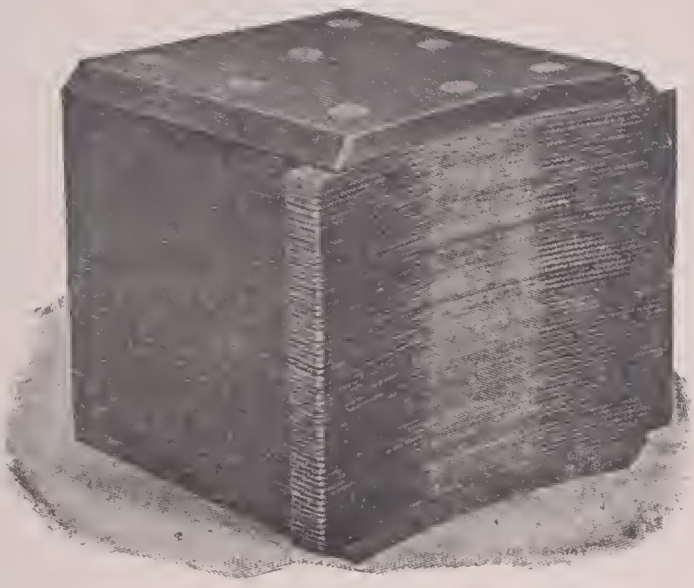

Fig. 238. Pole Piece and Core of Laminated Construction.

The Exciter.

To furnish the field current for all the alternators of a station two small D. C. generators are used, one being run while the other is being cleaned or held in reserve.

When storage batteries are in station it is often the custom to make each exciter of such a size as to carry continuously three-quarters of the field load.

When station is fully loaded, *i. e.* all alternators running, both exciters are run, and when load on station is light one exciter is shut down. In cases of exciter trouble the storage battery furnishes the field current.

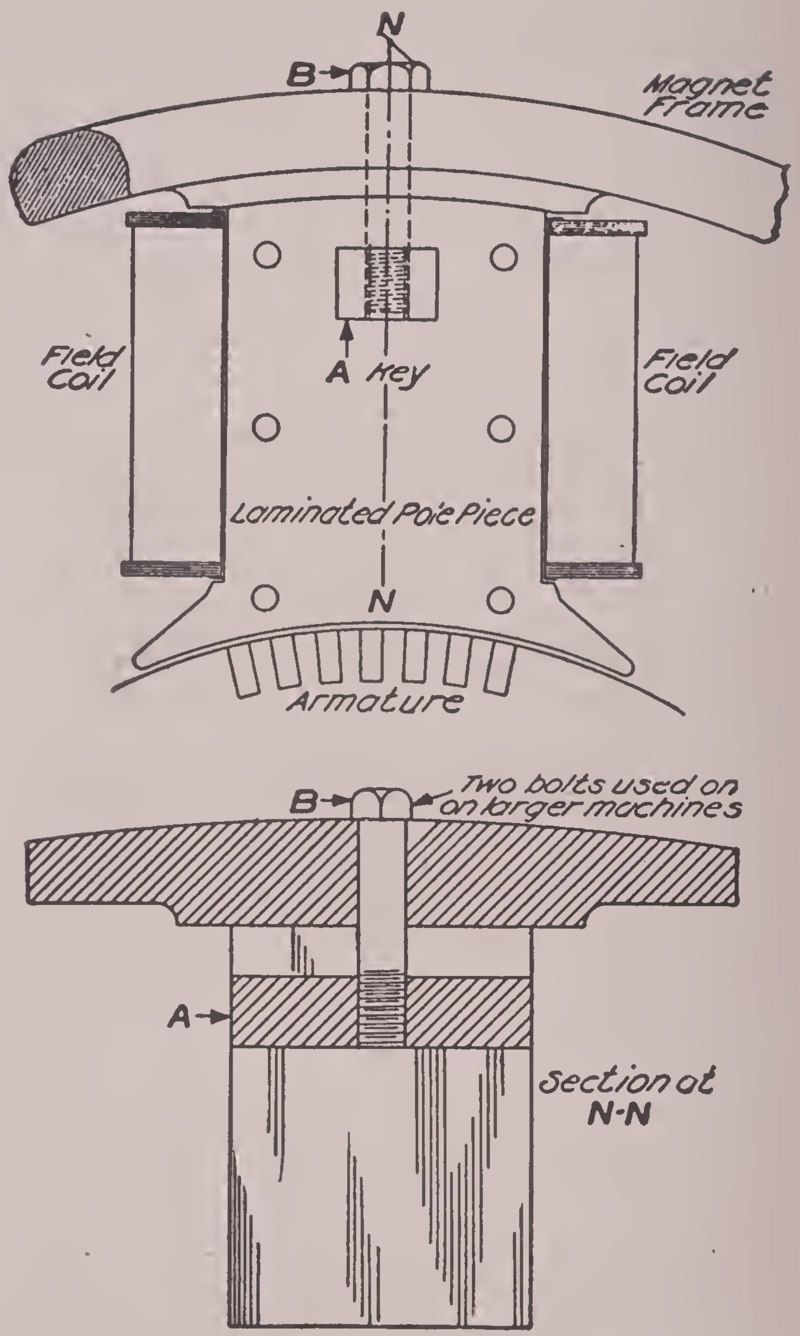

Fig. 239. Attaching Cores to Yoke.

Single Phase.

The field coils occupy about 50% of the surface of the field bore, because when their inner edges are tight together their outer edges are apart due to the larger circumference at the pole pieces, and because some interpolar space must be left to prevent excessive leakage from pole to pole.

Only 50% of the armature bore is wound, for otherwise the coils would be so wide that they would extend over into the field of a wrong pole piece. If one side of a coil is under a N-pole the other side should be under a S-pole. Then the two E. M. F.'s induced add together. Should the coil be so wide as to extend over to the next N-pole any E. M. F. induced by that pole would be subtracted.

There is then on the ordinary alternator half of the armature empty. Such a machine is called a Single Phase Alternator.

It occurred to some inventor that an entirely separate winding could be put on between the coils of the original winding and be connected to its own collector. The current was to be led to a different circuit, but it soon became evident that it was better to make of the four wires from the alternator a three-wire circuit by joining two of them inside the armature and leading out three wires to the switch board. Such an alternator is a Two Phase Alternator.

Of course the capacity of the machine is not doubled, because from a single phase alternator is drawn enough current to heat it to the safe limit. From a two phase alternator we do the same thing. The reason we gain in capacity is because in a single phase machine the heating is concentrated, while in the two phase machine it is evenly distributed all over the armature.

Even in a two phase alternator there is a portion of the armature not used for winding and there was still a desire to reduce the number of line wires. This led to the Three Phase Alternator.

The three armature windings of the alternator are connected together at one point and the other ends to the three collector rings or the three windings are connected in series and the three points where they are joined are connected to the three collector rings.

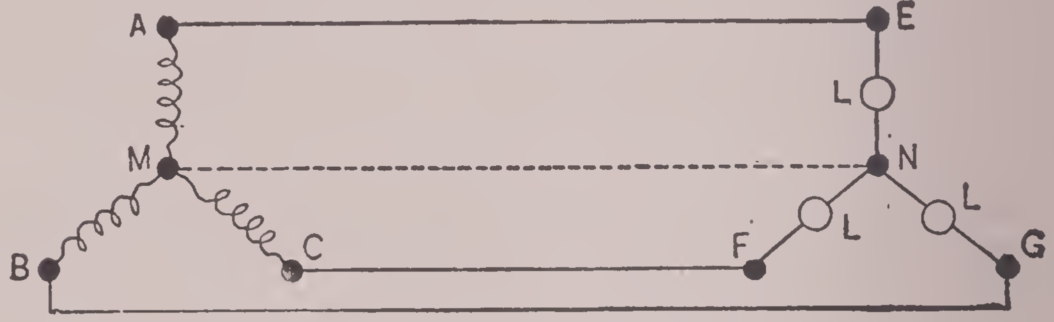

Fig. 239a. 3 Phase Y Connection.

The former winding is called a Y winding and is shown in Fig. 239a. The latter is a △ (Delta) winding and is shown in Fig. 239b. The European names are respectively Star and Mesh windings.

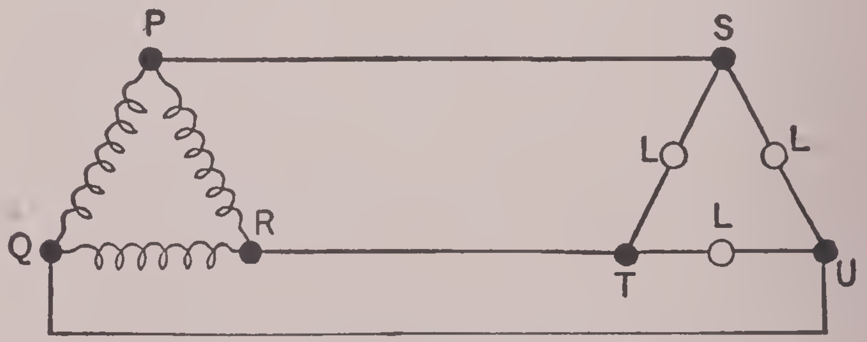

Fig. 239b. 3 Phase Delta Connection.

The three wires of a three phase system each act as a main wire and a return wire for one of the others at the same time. The actual current in the wire is the difference of the two currents: in and outgoing.

If the same three phase armature is connected first as a Y and then as a △ winding these differences will be noticed.

The Y armature will give the higher voltage and have less current capacity. The △ will give a lower voltage and have greater current capacity. Power that can be drawn from each is the same.

Transformers and other apparatus are wound two and three phase, and also Y and △ for use with the correspondingly wound alternator.

By a peculiar connection of coils rotary converters are wound for six phase currents; it having been discovered that it is possible to do so with the result of increased output for a given sized machine.

Two, three and six phase machinery is often grouped under name of polyphase.

LESSON 29.

Catechism on Dynamos,* Motors.†

The very brief answers given here may be added to by reference to the Lessons just studied.

Question 1. How is output of dynamo stated?

Answer. In Kilowatts equal to 1000×volts×amperes.

Question 2. How is output of motor stated?

Answer. In horse power, equal to Watts intake÷746, ×efficiency expressed decimally. (Not as a percentage.)

Question 3. What is voltage of a dynamo? of motor?

Answer. It is the pressure the generator or alternator delivers at its own terminals. The voltage of motor is the voltage which should be applied to its terminals in order to develop full horse power.

Question 4. What is full load current of dynamo? of motor?

Answer. Full load current of a dynamo is that current which may be drawn steady for 24 hours without causing any part of machine to exceed a safe temperature, *i. e.* 150° Fah. This applies to factory motors.

Of a railway motor it is the current which passing through motor for one hour as it runs on the blocks in testing room, will cause it to rise to a temperature of 212° Fah. We mean, of course, that the hottest part shall be no hotter than 212° Fah.

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*Includes all machines generating electricity, D.C. or A.C.

†Includes all machines utilizing electricity, D.C. or A.C.

Question 5. What is meant by the rating of a dynamo? Of a motor?

Answer. The product of full load current multiplied by the voltage expressed in Kilowatts is rating of a dynamo. The actual mechanical horse power developed at the pinion of the motor as tested in shop. The gearing increases the power applied to and reduces the speed of the car wheels.

Question 6. What is armature core?

Answer. The sheet iron body which carries the armature winding and conducts the flux from pole piece to pole piece.

Question 7. What is armature spider?

Answer. The casting consisting of hub and arms which supports armature core.

Question 8. What are binding wires?

Answer. They are narrow bands of phosphor bronze wire placed around armature every three or four inches to help bind winding to core. They rest on strips of mica and are sweated with solder all around.

Question 9. What are commutator segments?

Answer. The commutator segments or bars are the copper pieces of which the commutator is built.

Question 10. What are commutator leads?

Answer. They are the ends of the armature winding extending from core to the lug of the commutator bar.

Question 11. What are pole pieces?

Answer. The end of magnet core nearest the armature. Usually larger than core.

Question 12. What are magnet cores?

Answer. The iron inside the field coil.

Question 13. What is the yoke?

Answer. The part of magnetic circuit connecting the magnet cores.

Question 14. What is the pitch of an armature winding?

Answer. It is the number of teeth between the two sides of a formed coil plus one tooth.

Example: The two sides of a coil are in slots number 3 and 17, then pitch is 14.

Question 15. Is there insulation between winding and core?

Answer. Yes. Mica or fuller board; there is also the tape on coil.

Question 16. What insulation is there between conductors of winding?

Answer. The double cotton covering of each wire makes four thicknesses between conductors.

Question 17. What is the air gap?

Answer. It is the air space between armature and pole pieces. In dynamos it is made as small as possible for efficiency.

In motors it is not made too small because this tends to make machine spark due to the weak field. In D. C. series motors it is from ⅛ to ¼ of an inch, in A. C. series motor it is smaller, say 1/10 to ⅛ inch.

The larger the air gap of a motor the more the bearings may wear before there is danger of armature rubbing against lower pole pieces.

Question 18. What are field spools?

Answer. The brass shells on which the field coils are wound.

Question 19. What is the commutator?

Answer. It is a series of copper bars placed parallel to shaft, insulated from each other and from the frame of machine. Each is connected to the winding and current flows from winding through them to brushes. It at the same time reverses the connections between the brushes and winding at the proper times so that the brush always collects current.

Question 20. What is a collector or slip rings?

Answer. A collector consists of two or more rings of copper placed around the shaft and insulated from it and each other. Each is connected to a part of the winding. The brushes rest on the rings.

They are used to collect current from a revolving armature style of alternator, to feed current into armatures of rotary converters or the revolving fields of alternators.

The collector has no corrective influence and passes on the A. C. or D. C. current exactly as it receives it.

Single phase machines have two rings; two, three and six phase machines have three rings.

Question 21. Is there a difference between no load and full load voltage of dynamos?

Answer. Yes. A shunt dynamo gives highest voltage at no load and lowest at overloads; the series dynamo gives lowest at no load and highest at full load. The compound dynamo is a combination of series and shunt and gives some voltage at all loads. Fig. 240 will make this clear.

An alternator acts like a shunt dynamo.

Question 22. What is a field rheostat?

Answer. It is a resistance in the field circuit which can be varied to change the current, and hence the field strength. This alters the voltage of dynamo.

Question 23. What are commutated fields?

Answer. In some motors the field coils are arranged in sections so that they may be arranged in parallel or series, or in combinations.

All coils in parallel give the greatest current and hence slowest speed of motor; all coils in series give the weakest field and the fastest speed.

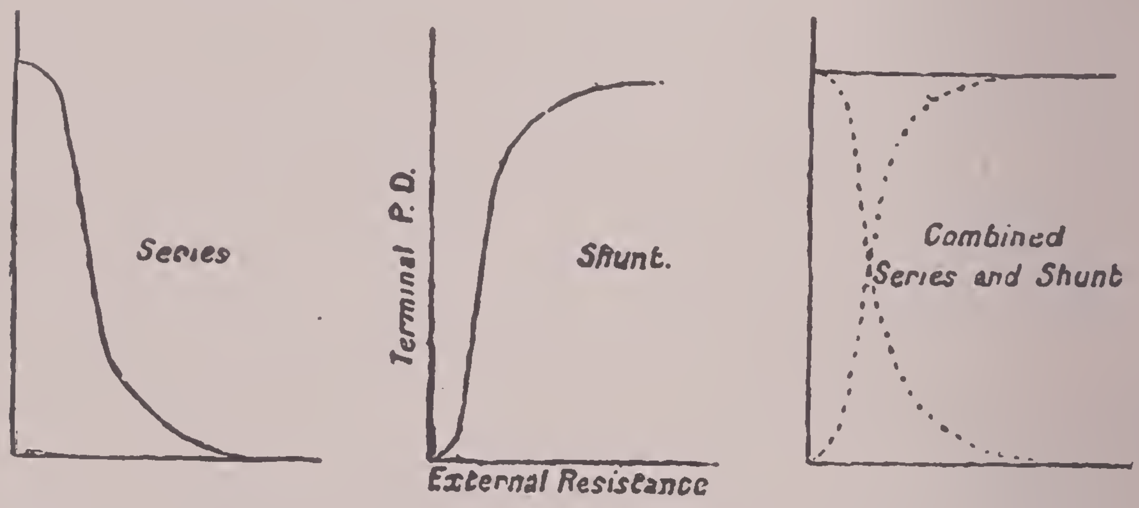

Fig. 240. Voltage Curves of Series, Shunt and Compound Dynamos.

Question 24. What relation has field strength to speed of motor?

Answer. The weaker the field the faster the speed, for the motor must revolve fast to generate its proper counter E. M. F.

Question 25. What relation has armature strength to speed of motor?

Answer. The greater the armature current the greater the speed.

Question 26. What effect on the power of motor does field and armature strength have?

Answer. The greater the field and armature current the greater the power.

Question 27. What is a ring winding?

Answer. One which passes over and under around the core, a space being left between shaft and core to accommodate winding.

Question 28. What is a drum winding?

Answer. One where all winding is on the outer surface of core.

Question 29. Upon what does sparkless commutation of current depend?

Answer. (1) The more commutator bars the better, there being less voltage and therefore tendency to spark between bars. The average railway motor has from 100 to 125 bars on commutator.

(2) The fewer the ampere turns on the armature in comparison to the ampere turns on the field the less sparking.

(3) The more turns short circuited by the brush when touching two or more bars at once the greater the tendency to spark.

Question 30. What is a shunt field?

Answer. One whose coils are placed as a shunt across the brushes. It carries a small current.

Question 31. What is a series field?

Answer. One which carries the main or nearly all the main current and is placed in series with the armature. A small strip of resistance metal is used sometimes to divert a portion of the main current from the series field.

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